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Arrowtooth Flounder

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On the cover:
Arrowtooth flounder,
Atheresthes stomias, is one of the
most abundant fish in the Gulf of Alaska.
Photo: Alaska Fisheries Science Center, NMFS, NOAA.

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The NMFS Southeast Region Headboat Survey: History, Methodology, and Data Integrity

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Introduction

The NMFS Southeast Region Headboat Survey (SRHS) is administered by the Beaufort Laboratory of the National Marine Fisheries Service's (NMFS) Southeast Fisheries Science Center (SEFSC). The SRHS samples recreational headboats, which typically carry more than 6 passengers. The survey has operated along the southeast U.S. Atlantic coast (SEUS) since 1972. It is the longest continuous time series of recreational fisheries data from federal waters in the SEUS.

The SRHS is composed of industry-reported trip data (referred to as "logbooks," "catch records," or "trip reports") from headboat trips and biological data collected dockside by SRHS port samplers from a subset of trips and anglers. Headboats (also referred to as "party boats") are distinct from charterboats, which almost always carry six passengers or fewer and charge one fee for the entire boat.

Anglers on headboats pay a per-head fee to target reef fish and coastal migratory pelagic species on full day (~ 8 h) or partial day (~ 4 h) trips. Some vessels can carry a maximum of nearly 100 passengers and may attain speeds of 25 kn although the average is typically 15 kn (Huntsman, 1976; Fig. 1).

The biological data collected are often used in stock assessments and in life-history studies. The SRHS samples many of the reef-associated and pelagic species managed by the South Atlantic Fishery Management Council (SAFMC). Scientists commonly use the data to estimate landings and to derive indices of abundance. For many stocks in the SEUS, this index is the only source of reliable abundance information prior to 1992, covering a critical time period in the exploitation history of those species. Our primary goal here was to explore the reliability of SRHS data collected from federal waters in the SEUS. We did this through two main lines of investigation: a) document the history, protocols, and methodological changes to the SRHS, and b) estimate the prevalence of apparent or likely misreporting in the survey.

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ABSTRACT—The Southeast Region Headboat Survey (SRHS) is administered by the Beaufort Laboratory of the NMFS Southeast Fisheries Science Center. The SRHS samples recreational headboats, wherein fishermen pay by the "head" and boats typically carry more than 6 passengers. The survey has operated along the southeast U.S. Atlantic since 1972 and in the Gulf of Mexico since 1986. It is the longest continuous time series of recreational fisheries data from federal waters along the southeast coast. The SRHS data consist of trip-level logbook records submitted by captains and biological samples collected dockside by professional port agents. Our study, focused on the SRHS in southeast U.S. Atlantic, was initiated a) to document the history, protocols, and methodological changes to the SRHS, and b) to estimate the prevalence of misreporting in the survey. We recommend that our results be used to guide the filtering of logbook records containing apparently erroneous information. However, more generally, our results indicate that the SRHS data are robust. We expect the survey will continue to support stock assessments, management advice, and other studies of economically important fish species.

History, Methodology, and Protocols

History of the Headboat Fleet and Survey

Prior to 1970, exploration of the continental shelf off of North Carolina and South Carolina was mainly limited to commercial fishing methods targeting demersal fish concentrations and usually avoided areas not amenable to trawl gear (Huntsman, 1976). The headboat fishery developed in the SEUS in the 1920's and 1930's at a relatively small scale but became more prevalent in the SEUS in the mid-1960's.

During this early period, headboat captains often fished commercially when tourist activity was low and operated headboat trips when profitable. Most vessels were wooden and fished close to shore (i.e., within sight of land). Following World War II (1945), U.S. military boats became available to the public as surplus, and many were purchased for use as headboats (Huntsman, 1976). These vessels were technologically advanced for this time period, with significant horsepower and steel hulls that were capable of carrying many passengers.

Fishing off South Carolina's Little River was detrimentally impacted in 1954 following a direct landfall of Hurricane Hazel (Burrell, 2000), and only two headboats remained in the fishery. In the winter of 1958 off the North Carolina coast, unusually cold

Figure 1.—Headboat vessel, *Little Critter,* in southeast U.S. Atlantic in the 1970's.

water intruded onto the continental shelf, resulting in widespread mortality of demersal fishes (McLain et al.[1]; Simpson[2]). The magnitude of this event was not fully quantified but commercial landings of snapper-grouper species declined from nearly 135 metric tons (t) in 1957 to nearly zero the following year (Power, 1959).

From the 1940's through the 1960's the headboat fishery steadily expanded geographically as did the number of vessels participating. Headboat operations were located near barrier island inlets in coastal towns such as Morehead City and Carolina Beach, North Carolina; Little River, Murrells Inlet, and Charleston, South Carolina; Mayport, St. Augustine, Ponce Inlet, Jupiter, Miami, and Key West, Florida (Fig. 2).

Ellis et al. (1958) estimated that in 1955 there were 164 headboats operating in Florida waters, 83 on the east (Atlantic) coast and 81 on the west (Gulf) coast. Huntsman (1976) reported that about 25 headboats operated from Cape Hatteras, N.C., to Charleston, S.C., from 1972 to 1973. Estimates of the annual number of headboats operating in the SEUS have fluctuated since the early 1970's, ranging from 32 to 99. From the 1980's to the 1990's the number of headboats was relatively constant in the SEUS, with about 70–80 vessels. A decline in the number of headboats began in the early 2000's, likely due to multiple factors, including declining fish stocks, more restrictive regulations, and other economic factors (e.g., high operational costs and increases in the number of private fishing vessels).

Tackle used during headboat trips is sturdy enough to resist abrasion from heavy fish and hard bottom structure, as well as the stresses of frequent use often by inexperienced anglers (Huntsman, 1976). Solid, 5- to 6-ft, fiberglass rods are standard. Typically, reels are size 6/0 to 9/0 and line is 80–120-lb test monofilament. During the 1970's in North Carolina and South Carolina, electric reels were used on a small number of headboats to improve efficiency while increasing catch rates, primarily in deeper waters. The bottom rigs consist of small to medium size "J" and circle hooks, usually two per rig.

A typical full-day trip begins at daybreak and lasts approximately 8–10 h. Headboats fish in depths from ~ 25 to ~ 145 m (Huntsman, 1976). After transit to the fishing ground, anglers spend about 6–8 h fishing before returning to port. Captains tend to avoid fishing at greater depths due to increased tangling, and because stronger currents in those depths often prevent the lines from reaching the bottom. Depending on conditions, captains may anchor before angling begins, or may allow clients to fish while the vessel drifts.

Headboats often target species contained in the SAFMC Snapper Grouper complex.[3] Distributions of snapper-grouper species are dependent on many factors, with latitude and depth among the most important (Shertzer and Williams, 2008). A complex, inner-shelf (<30 m) community, dominated numerically by species such as black sea bass, *Centropristis striata;* grunts (Haemulidae), and porgies (Sparidae), is present from North Carolina to Cape Canaveral, Fla. The mid-shelf region (30–100 m) is populated by a diverse group of species, whose distributions often extend into shallower or deeper waters, including but not limited to red porgy, *Pagrus pagrus*; vermilion snapper, *Rhomboplites aurorubens*; red snapper, *Lutjanus campechanus*; gray triggerfish, *Balistes capriscus*; red hind, *Epinephelus guttatus;* scamp, *Mycteroperca phenax;* speckled hind, *Epinephelus drummondhayi*; and knobbed porgy, *Calamus nodosus* (Grimes, 1978; Chester et al., 1984). A distinctive community of deepwater (>100 m) groupers (*Epinephelus*, *Hyporthodus,* and *Mycteroperca*) occurs at and beyond the continental shelf edge. A gradual shift in the species assemblage occurs south of Cape Canaveral where gray snapper, *Lutjanus griseus*; lane snapper, *L. synagris;* mutton snapper, *L. analis;* and

[1]McLain, D. R, F. V. Mayo, and M. J. Owen. Monthly maps of sea surface temperature anomalies in the northwest Atlantic Ocean and Gulf of Mexico, 1948–1967. Unpubl. manuscr. Pac. Environ. Group, Natl. Mar. Fish. Serv., NOAA, c/o Fleet Numerical Weather Central, Naval Post Graduate School, Monterey, CA 93940, 13 p.

[2]Simpson, B. 1974. Headboats divulge catch figures to NMFS, aid Carolina fishery. Natl. Fisherman Mag. 54(7), 10 p.

[3]See http://safmc.net/resource-library/snapper-grouper.

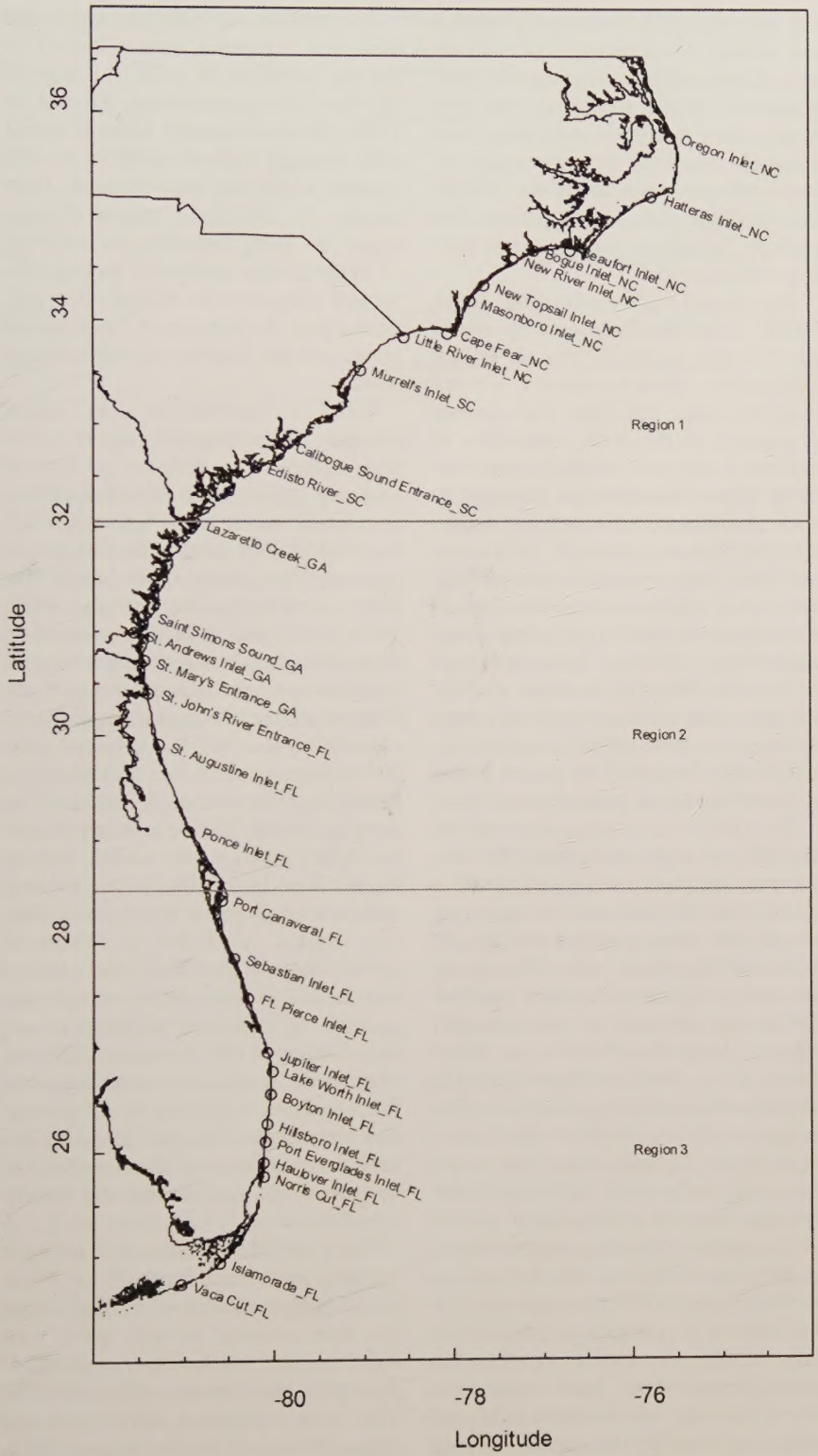

Figure 2.—Common fishing inlets used in the headboat fishery in the Carolinas, Georgia-northeast Florida, and southeast Florida regions. The three regions were used for species-specific catch record analyses.

yellowtail snapper, *Ocyurus chrysurus,* are more prevalent (Shertzer et. al., 2009).

In the early 1970's, SEFSC staff recognized that the recreational headboat fishery accounted for substantial landings for many of the species listed above (e.g., 725 t of marketable fish landed in 1973 from the Carolinas (Huntsman, 1976)). As a result, the SRHS was initiated in 1972 in North Carolina and South Carolina by NMFS staff at the SEFSC Beaufort Laboratory, with the objective of monitoring the headboat fishery and collecting biological samples dockside to determine average weights by species and to estimate total removals by weight. In 1976 the survey expanded to Georgia and northeast Florida (Nassau-Indian River counties), and then to southeast Florida (St. Lucie-Monroe counties) in 1978. In the early decades (1972–91) of the SRHS, these data were the primary source of fishery-dependent information on age and growth, and on relative abundances of fishes in the snapper-grouper complex.

Methodology

The SRHS survey design incorporates logbook reporting from headboat vessels and dockside sampling by NMFS port agents. The SRHS is divided into discrete geographic/statistical areas to which headboat trips are assigned and landings estimated. The three main components of the SRHS data collection are the dockside intercept sampling program (DISP), the headboat activity report (HAR), and the logbook, commonly called the trip report or catch record (CR).

The DISP obtains length and weight data from landings to determine the size distribution and mean size of species landed by the headboat fishery. Port agents also collect otoliths, spines, and occasionally gonads to characterize age distributions, sex ratios, and reproductive traits. Port agents may collect other biological samples (e.g., stomachs, fin clips) in support of specific research projects or management needs (e.g., trophic interactions, stock structure).

The survey design for the DISP can best be described as a systematic opportunistic design. Each port agent assigned to a particular area is required to sample all headboats within their area of responsibility in a systematic rotation, ideally sampling each vessel at least once each month during periods of operation. In some areas, headboat trips occur year-round (e.g., southeast Florida), while in other areas there are periods (typically winter) during which no trips occur (e.g., North Carolina and South Carolina). The operational schedules of individual vessels show considerable variation, and it is rare that agents are able to sample vessels in an exact and repeatable rotation. Consequently, SRHS port agents can adjust their sampling schedules to ensure sampling of all vessels approximately the same number of times each month during periods of operation.

When conducting dockside intercept sampling, port agents are instructed to identify themselves as NMFS port agents conducting a survey of headboat fishing. They are further instructed to identify and select anglers with unusual, uncommon, or rare species in their catches (on stringers, in coolers, etc.). The rationale for this approach is that if catches with uncommon fish are selected, sufficient numbers of more common species will likely be obtained as well. Port agents are instructed to measure and weigh all fish from selected catches. However, once they have measured 10 fish of a given species, they are not required to (but may if time allows) measure additional individuals of that species from additional catches sampled from that trip. This approach allows port agents to spend more time collecting information on less common species while collecting sufficient information on more common species.

Upon obtaining an angler's catch for sampling, the port agent measures and weighs individual fish, typically using an electronic fish measuring board connected to an electronic balance, but at times (historically and currently if there are equipment malfunctions) using non-electronic measuring boards and scales. All measurements are recorded into computer memory for later download. While sampling, the port agent often performs education and outreach functions by answering bystanders' questions about the SRHS, fish biology, fish identification, fish ecology, fisheries regulations, and fisheries management.

The second main component of the SRHS is the headboat activity report (HAR). Port agents record all known information about a vessel's activity (e.g., trip date, trip type, and number of anglers) on the HAR, regardless of whether a trip was sampled under the DISP. These observations are used to track compliance (a vessel is compliant if all trips are reported) and to correct for misreporting or non-reporting. The HAR observations are collected by multiple methods including direct observation, contact with the vessel's ticket office to confirm activity, incorporation of observations made by samplers from other surveys (e.g., MRIP samplers) and, in recent years, by checking websites for fishing trips.

The third main component of the SRHS is the logbook report (CR). The CR was originally designed to be a census, but fluctuations in reporting cooperation have resulted in changes in methodology over time. The survey has always asked or required (see below) vessel personnel to complete self-reported logbooks of catch and effort for each trip. From 1972 to 2012 the mechanism used by captains and crew to report catch and effort was a one-page, paper logbook form. The paper form originally used in North Carolina and South Carolina listed several of the most commonly caught species in the Carolinas. As the survey expanded in the SEUS, the logbook form was altered to reflect the species typically caught in specific geographic areas. Unique forms were created for North Carolina, northeast Florida, and southeast Florida. Due to the limited amount of space (one page), the form for each geographic area contained only those species that were most likely to be kept in that region.

The number of species on a single form has expanded from a low of 24 for the Carolinas in 1972 to a high of 74 for Georgia-northeast Florida in 1986. The area-specific logbook forms also changed several times to accommodate additional data elements (Appendix 1). The most recent change, made in 2004, included the addition of fields for the number of paying customers who actively fished on a particular trip, the number of fish released alive, and the number of fish released dead.

Table 1 summarizes the major changes to the logbook report forms and includes the addition of species and trip information. Sixteen different forms were used between 1972 and 2013, with subtle changes occurring more frequently in the late 1970's and major changes occurring in 1980, 1984, 1992, and 2004 that correspond to increased data needs, major regulatory changes, and increases in computer memory and processing capabilities.

In 2009, the SRHS conducted a pilot project to test the feasibility of developing an electronic logbook reporting system. Software was installed on eight vessels in the SEUS: two in North Carolina, two in South Carolina, one in Georgia, and three in Florida. The project concluded in November 2010. The results from this project and feedback from captains were favorable regarding the application and ease of use of the electronic logbooks (Appendix 2). Project results indicated that electronic reporting would streamline data collection and facilitate the timely completion of data analysis to support stock assessments and fishery management.

The SRHS electronic logbook (eLog) was implemented in 2013. Since implementation, the SRHS eLog has been updated several times, with most updates restricted to minor adjustments that did not affect the user. The most significant update that did impact the user was in August 2014, when four socioeconomic fields were added: number of paying passengers, number of crew, amount of fuel used, and price per gallon of fuel.

Table 1.—Summary of the changes documented in southeast Regional Headboat Survey (SRHS) forms used in the southeast U.S. Atlantic headboat fishery, 1973–2004.

Year	Form #	No. of species	Black sea bass (units)	Discards	Additions to header/master information and other major changes
1972	1	24	No. of 100 lb. boxes		Number captured, vessel, date, number of anglers aboard
1976	2,3,4,5	(NC/SC): 35 (GA/FL): 32	No. of 100 lb. boxes		(Florida added), location, full, 1/2, and 3/4 day
1978	4,5,6,7	(NC/SC): 35 (GA/FL): 31	Pounds		a.m., p.m.
1980	8,9	(NC/SC): 36 (GA/FL): 67	Pounds	Hand written by species, inconsistent	Night, overnight, captain signature, blank lines to add in species and number discarded
1984	10,11	(NC/SC): 62 (GA/FL): 71	Pounds	Hand written by species, inconsistent	Number Captured changed to Number Caught, Night (1st, 2nd), Departure Time, agency use only section
1986	12,13	(NC/SC): 64 (GA/FL): 74	Pounds	Hand written by species, inconsistent	King Mackerel, Spanish Mackerel, Cero, Dolphin, Cobia, Little Tunny above bold black line with mandatory reporting statement "It is unlawful to falsify or fail to report...". Added in July, deleted in October.
1992	14,15	69	No. and wt. (SC released on few forms)	South Carolina only - very few vessels, released ('92-'03), released alive and dead ('00-'02)	
2004	16	69	No., wt., released alive, released dead	Released alive and dead standard on all forms and areas	Distance from shore, pay type, number of anglers who fished

Currently the SRHS eLog requires the following fields to be completed for each trip: date(s) and duration of the fishing trip; vessel and captain's names; number of anglers and number of paying passengers; number of crew, number of gallons of fuel used, and price per gallon of fuel; geographic location of fishing activity in latitude and longitude degrees and minutes (optional point and click maps); minimum and maximum of primary depths fished; number of individuals of each caught species that were kept; and number of individuals of each caught species that were released either alive or dead.

From 1972 to 1995, logbook reporting was voluntary for headboats participating in the SRHS. Starting in 1972, as part of the strategy to encourage captains to report, participating vessels in the SEUS were paid for reporting. The amount of payment was related to the length of a trip, which in turn affected the size and complexity of the catch. Vessel personnel were paid $1.50 for each record of a "full" day trip, $1.25 for a "three-quarter" day trip, and $1.00 for a "half" day trip.

Payment for participation in the SEUS survey continued until logbook reporting became mandatory in 1995 with Amendment 7 to the Snapper-Grouper Fishery Management Plan (Code of Federal Regulations 646.4). This amendment required charter vessels and headboats to be in possession of a permit in order to fish for snapper and grouper. As a condition of this permit, the reporting requirements (FR 622.5) state "charter vessel/headboat owners and operators that if selected to report by the SEFSC, must maintain a fishing record for each trip." The rule further states that headboats are required to report on a monthly basis by submitting logbooks within seven days of the end of each month. From 1995 to 2013, reporting requirements were unchanged.

In January 2014, NOAA published a final rule for the For-Hire Reporting Amendment (Amendment 31 to the Fisheries Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region, Amendment 6 for the Dolphin and Wahoo Fishery of the Atlantic, and Amendment 22 for the Coastal Migratory Pelagic Resources in the Atlantic and the Gulf of Mexico) which modified headboat reporting requirements for the SEUS. The notable changes addressed when and how to report. First, the rule required headboat personnel to submit fishing records to the SEFSC on a weekly basis. Second, the rule changed the method of submission from mailing paper forms to submitting forms electronically. Third, the rule prohibited headboat owners and operators who are delinquent in submitting reports from continuing to harvest or possess snapper-grouper and coastal migratory pelagic species until they have submitted the required reports.

Protocols

Since the inception of the SRHS, the broad objective to characterize the headboat fleet has remained the same while subtle changes in data collection practices have occurred to address an increase in management needs, or to actively improve the survey using current technologies (e.g., the change from paper to electronic reporting; the change from monthly to weekly reporting to support monitoring needs needs). Although the data management practices in the early years of the program were not well documented, the goals were always clear: summarize effort and landings while accounting for missing or incomplete records. All landings and effort estimates, including correction factors (adjustment for missing catch records), were calculated manually in the early years.

In recent years, reported effort has been summed by month and vessel after converting number of anglers to angler days. An "angler day" is the amount of effort expended by one angler, using rod and reel, on a full day fishing trip (usually 8 h), and includes travel time to and from the fishing grounds (e.g., 40 anglers on a half-day trip would yield 20 angler days). To adjust for incomplete reporting, information summarized on a HAR is used to estimate total effort. Total estimated effort (estimated angler days) is then divided by reported effort (reported angler days) to calcu-

late a correction factor used to adjust reported landings.

Landings estimates are provided by species, area, and month. Effort correction factors are calculated by month and vessel to adjust for misreporting. These correction factors are applied to the reported landings by species-vessel-month combinations to generate total estimated numbers of fish landed. These numbers are then multiplied by mean weights of fish calculated from the biological profile (BP) data by species-area-month combinations to generate a total weight of fish landed for each species-vessel-month combination. These fine-scale estimates are then summed at courser scales to provide landings estimates for stock assessments and quota monitoring.

Historically, logbooks submitted substantially late were counted as missed trips so that estimates of landings and discards were not subjected to substantial recall bias. For such cases, landings and discard data were subsequently estimated using conversion factors. However, the specific policy defining "substantially late" was not documented, and decisions may have been made on a case-by-case basis based on guidance from the local port agent. Once the logbooks were received at the Beaufort Laboratory, survey personnel checked them again to ensure there were no obvious errors. Data entry contractors used key entry verification procedures (data were entered twice, and the two datasets compared to one another) to ensure that data were entered correctly.

Current quality assurance procedures within the database (SRH Oracle system[4]) focus mainly on the BP data. Port agents load BP data directly from the electronic fish measuring board (FMB) text files into the SRH Oracle system. When not using FMB's, port agents will record measurements on a paper form and enter the data directly into the SRH Oracle system through a data entry form. The FMB text files contain various delimiters. The Oracle upload system checks that these delimiters are in place and are valid; if any delimiters are entered incorrectly the upload is rejected. The Oracle system also rejects any upload where the species codes do not match. Once the data are loaded, the port agents are instructed to review each collection for accuracy and completeness.

[4]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Analysis of Data Integrity

Methods

The self-reported SRHS data lack any independent validation source, relegating any analysis of potential misreporting to methods of outlier detection. The misreporting analysis focused on data spanning 41 years (1972–2013) and involved two main components: 1) analysis of industry-reported catch records (CR's) to identify outliers, which might be indicative of misreporting, and 2) comparison of trip-level catch records with data collected by SRHS port agents (BP's) during DISP surveys. Both components are described below.

Outlier Analysis

The self-reported CR's were analyzed using two lines of investigation. The first approach focused on the landings of individual species reported, and the second approach examined the species composition of reported trips from vessels operating in southeast U.S. Atlantic water. For both of these approaches, comparisons were made among vessels from similar geographic locations that would be expected to fish in similar areas and, therefore, show similar trends in landings. In addition, comparisons were made within distinct time periods, to account for changes in fleet dynamics over time. Fifteen area-time blocks (Table 2) were developed using inlet information (Fig. 2) and multivariate statistical techniques similar to those of Shertzer et al. (2009) were applied, resulting in three distinct spatial areas. Regulatory changes in the fishery were reviewed to determine time periods. These area-time blocks were used to define common patterns in catches, and to identify individual vessels that deviated from the common patterns (i.e., outlier vessels). Outlier vessels were investigated to determine whether deviations in catch could be explained by unique characteristics of particular vessels or whether misreporting was a more likely explanation.

Species that were present in at least 15% of headboat trips in at least one of these 15 area-time blocks were included in the analysis. Various methods were examined to identify species to include in the analysis (i.e., all species, present in 1–10 % of trips) but 15% was chosen as the "cutoff" to maximize the number of species that were encountered in all 15 area-time blocks. In some cases, a species was rare in one area and common in another because of changes in species assemblage structure with latitude (Shertzer et al., 2009).

Analyses of the CR's were conducted to identify individual vessels within each area-time block combination (n = 15) that were outlier vessels and, therefore, potentially misreporting. A single vessel could be identified as an outlier vessel in multiple area-time blocks. These analyses relied on 62 metrics designed to flag different types of potential misreporting associated with various species (Table 3). Fifty of these metrics (two metric types X 25 species) (metric numbers 5 and 10 in Table 3) focused on the reported landings of 25 individual species, and twelve focused on metrics describing species compositions (metric numbers 1–4, 6–9, 11, and 12 in Table 3). With 637 vessel-area-time block combinations and 62 metrics, there were 39,494 metrics that could potentially be flagged. For detecting outliers, we used a modified z-score computed as,

$$z = (0.65\ (x_i - x) / \mathrm{MAD}),$$

where MAD denotes the median absolute deviation, x_i is the value of a particular metric for vessel i, and x is the median of that particular metric for all vessels in a particular area-time block (Iglewicz and Hoaglin, 1993; Hammer et. al., 2010). A modified z-score was defined as an outlier if $|z| > 3.5$

Table 2.—Bold values represent species kept in at least 15% of headboat trips indicating common species in the Atlantic used in the species-specific catch record (CR). Value represents the proportion of trips with at least one species recorded within area-time blocks. Excluding Black Sea Bass and Bank Sea Bass, the species in this table were used for the species-specific catch record (CR) analyses.

		Carolinas					Georgia & North Florida					South Florida				
Common Name	Scientific Name	1972–1983	1984–1991	1992–2000	2001–2009	2010–2013	1972–1983	1984–1991	1992–2000	2001–2009	2010–2013	1972–1983	1984–1991	1992–2000	2001–2009	2010–2013
Black Sea Bass	*Centropristis striata*	**79.3**	**86.6**	**75.7**	**70.6**	**59.7**	**78.4**	**82.3**	**59.4**	**66.6**	**66.0**	4.8	9.3	11.3	**20.9**	11.4
Vermilion Snapper	*Rhomboplites aurorubens*	**31.4**	**29.9**	**41.6**	**32.7**	**20.8**	**82.5**	**90.6**	**54.1**	**83.0**	**58.8**	**20.7**	**23.7**	11.5	12.3	10.7
Gray Triggerfish	*Balistes capriscus*	**30.6**	**22.4**	**43.0**	**34.5**	**29.5**	**51.2**	**52.6**	**50.9**	**59.7**	**71.3**	**19.6**	**26.4**	**21.9**	**26.3**	**31.4**
Tomtate	*Haemulon aurolineatum*	**33.6**	**46.3**	**45.9**	**24.6**	**28.4**	**57.2**	**86.7**	**44.1**	**17.0**	**25.2**	8.7	**16.6**	9.0	8.0	8.7
Gag	*Mycteroperca microlepis*	**24.0**	**25.5**	**23.9**	**19.6**	14.8	**49.6**	**43.1**	**50.7**	**33.1**	**18.3**	10.6	9.4	12.1	12.5	2.6
King Mackerel	*Scomberomorus cavalla*	1.2	12.7	**21.8**	**19.0**	8.6	**21.0**	**18.9**	**16.6**	**17.0**	5.6	**51.3**	**45.8**	**34.9**	**31.5**	**28.2**
Gray Snapper	*Lutjanus griseus*	0.1	0.3	1.2	2.6	0.4	**21.4**	**29.2**	**45.4**	**42.8**	**29.2**	**17.9**	**25.2**	**39.3**	**41.4**	**35.3**
Red Snapper	*Lutjanus campechanus*	**16.0**	**15.4**	12.8	10.8	0.4	**69.9**	**52.4**	**46.5**	**72.3**	2.2	5.1	5.6	5.5	13.1	0.4
White Grunt	*Haemulon plumierii*	**26.1**	**26.8**	**44.1**	**38.5**	**34.6**	0.6	2.5	7.6	4.2	5.3	10.9	**18.5**	**28.9**	**36.4**	**31.4**
Whitebone Porgy	*Calamus leucosteus*	10.3	**18.4**	**31.1**	14.0	6.3	**21.2**	**51.8**	**43.1**	**33.4**	**45.9**	1.6	3.5	4.0	5.9	9.2
Yellowtail Snapper	*Ocyurus chrysurus*	0.1	0.3	0.6	0.8	0.2	5.1	11.4	2.2	10.9	2.1	**50.8**	**48.1**	**54.2**	**52.1**	**54.2**
Red Porgy	*Pagrus pagrus*	**44.0**	**34.2**	**31.0**	**25.6**	**16.3**	**42.6**	**24.4**	9.8	11.1	5.7	6.4	6.6	1.3	0.7	1.7
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	0.0	0.3	14.3	**22.3**	**36.1**	0.0	4.5	**44.6**	**53.1**	**48.0**	0.0	0.1	3.5	11.8	7.4
Greater Amberjack	*Seriola dumerili*	13.0	**17.7**	**17.3**	14.6	10.9	**41.2**	**30.0**	**27.5**	**29.2**	**21.8**	8.4	6.2	3.1	3.5	1.6
Lane Snapper	*Lutjanus synagris*	0.0	0.0	0.1	0.0	0.0	11.6	**15.1**	**35.8**	**40.8**	**19.4**	10.3	**22.3**	**29.0**	**28.3**	**19.4**
Mutton Snapper	*Lutjanus analis*	0.1	0.0	0.1	0.1	0.2	3.2	3.9	7.5	8.6	5.1	**44.3**	**36.3**	**31.3**	**31.6**	**29.7**
Little Tunny	*Euthynnus alletteratus*	0.1	4.3	7.3	4.5	5.4	4.4	**23.9**	**15.7**	7.1	6.8	10.1	**31.9**	**20.7**	14.9	**24.1**
Scamp	*Mycteroperca phenax*	**22.4**	**25.7**	**28.7**	**22.3**	11.4	5.6	7.2	**19.6**	**16.8**	4.7	4.4	3.6	3.1	3.2	0.6
Blue Runner	*Caranx crysos*	0.4	1.3	1.6	1.4	0.6	1.0	4.3	1.4	2.1	1.4	**29.1**	**31.2**	**21.9**	**16.6**	**25.7**
Spottail Pinfish	*Diplodus holbrookii*	12.5	**17.3**	**19.2**	**23.0**	**28.9**	0.5	10.9	13.0	6.1	5.9	0.1	0.0	0.1	0.3	0.1
Cobia	*Rachycentron canadum*	0.5	2.4	4.4	4.4	3.3	7.7	**18.4**	**19.7**	**26.1**	**21.7**	4.7	4.5	6.0	5.8	7.2
Red Grouper	*Epinephelus morio*	3.5	2.8	12.1	10.4	3.2	**15.8**	8.0	7.8	7.5	1.6	13.0	10.5	**16.5**	**17.7**	6.1
Knobbed Porgy	*Calamus nodosus*	10.4	**17.9**	**22.1**	9.8	2.8	2.0	1.5	0.6	0.5	0.3	9.3	10.8	9.3	14.3	11.1
Bank Sea Bass	*Centropristis ocyurus*	0.0	13.5	**21.5**	**15.0**	12.6	0.0	**26.3**	11.1	9.1	9.4	0.0	0.1	0.2	0.2	0.2
Great Barracuda	*Sphyraena barracuda*	0.2	2.9	4.1	2.8	1.3	2.8	10.6	**17.5**	**15.8**	14.2	**16.3**	8.9	8.6	3.5	1.6
Sand Perch	*Diplectrum formosum*	0.3	11.4	6.3	4.5	3.3	0.9	**21.9**	4.2	1.6	1.5	0.1	0.5	0.3	0.6	0.8
Atlantic Bonito	*Sarda sarda*	0.0	1.1	0.3	0.2	0.3	9.3	0.0	0.0	0.0	1.5	**20.4**	0.0	0.0	0.0	2.0

(Iglewicz and Hoaglin, 1993). Data from vessels with flagged metrics were examined further to identify potential explanations (e.g., presence of inshore species on logbook, indicative of inshore fishing and thus not suggestive of misreporting).

The second approach investigated variations in species composition of the catch among vessels within each area-time block. Non-metric multidimensional scaling (NMDS) was applied in three-dimensional Euclidean space (McCune and Grace, 2002). Euclidean distance measures from the origin were transformed to modified z-scores to identify outlier vessels. A flagged metric (outlier) indicates a significant deviation from the median, whether the median is the median number of fish caught, the median number of anglers, or the species composition in that area-time block.

Trip-level CR-BP Analysis

The BP data collected dockside were compared with the logbook records (CR's) from those same trips to identify discrepancies indicative of catch misreporting. BP records cannot be matched directly to a CR, so vessels and data were used to match records.

After assessing multiple approaches to identifying individual trips, we determined that the optimal approach was to use vessel number and date to identify individual trips. Because some vessels can make more than one trip in a single day, the matching analysis was constrained to trips on dates for which a vessel was sampled and reported a single trip.

The number of fish measured in the BP data were compared to the number of fish reported on the CR's for

Table 3.—List and description of metrics developed to identify misreporting used by vessel for the species-specific catch record (CR) analyses.

Metric Number	n	Type of potential misreporting	Description
1	1	Consistently report high or low number of total catch	Relative ranking of the mean of reported catch among vessels by area and time period
2	1	Consistently report high or low catch rates	Relative ranking of the mean of reported CPUE among vessels by area and time period
3	1	Consistently report high or low number of species	Relative ranking of the mean of reported count of all species among vessels by area and time period
4	1	Consistently report very few species or many species	Relative ranking of the mean of the Shannon-Wiener index value among vessels by area and time period
5	25	Consistently report low or high numbers of species 'x'	Relative ranking of the mean catch for each of 25 species among vessels by area and time period
6	1	Consistently report the same number of individuals	Relative ranking of the variance of reported catch among vessels by area and time period
7	1	Consistently report the same catch rates	Relative ranking of the variance of reported CPUE among vessels by area and time period
8	1	Consistently report the same number of species	Relative ranking of the coefficient of variation of reported count of all species among vessels by area and time period
9	1	Consistently report the same level of species diversity at the trip level (similar to spcount.cv)	Relative ranking of the coefficient of variation of the Shannon-Wiener index value among vessels by area and time period
10	25	Consistently report similar catch rates for species 'x'	Relative ranking of the variation in CPUE for each of the 25 species among vessels by area and time period
11	2	Report species that are much different than similar vessels fishing in similar habitat	Non-metric multi-dimensional scaling (NMDS) - presence/absence of 25 species
12	2	Report species catch rates that are much different than similar vessels fishing in similar habitat	Non-metric multi-dimensional scaling (NMDS) - CPUE of 25 species

Table 4.—Number of reported trips, estimated trips, and reporting compliance rate (defined as reported trips no more than 8 days after the fishing week/estimated trips) from the Southeast Region Headboat Survey, 1980–2013. The number of reported and estimated trips were not available in electronic format prior to 1980.

	Headboat fishery		
Year	Reported Trips	Estimated trips	Compliance rate
1980	11,435	24,724	0.46
1981	11,395	24,134	0.47
1982	12,353	25,520	0.48
1983	12,195	24,534	0.5
1984	11,280	22,871	0.49
1985	11,187	22,630	0.49
1986	13,990	24,128	0.58
1987	14,152	25,123	0.56
1988	12,103	23,457	0.52
1989	10,982	23,853	0.46
1990	11,432	24,624	0.46
1991	10,844	25,382	0.43
1992	15,154	22,377	0.68
1993	14,011	20,009	0.7
1994	12,708	21,412	0.59
1995	12,405	19,595	0.63
1996	9,200	19,270	0.48
1997	6,429	16,559	0.39
1998	9,372	15,237	0.62
1999	7,746	15,831	0.49
2000	7,865	16,980	0.46
2001	7,002	14,917	0.47
2002	5,779	13,323	0.43
2003	5,752	12,086	0.48
2004	6,509	15,090	0.43
2005	5,857	14,876	0.39
2006	6,162	15,363	0.4
2007	6,608	14,451	0.46
2008	9,492	11,627	0.82
2009	10,718	11,670	0.92
2010	11,489	12,090	0.95
2011	11,537	12,018	0.96
2012	12,423	13,222	0.94
2013	13,764	14,708	0.94

Table 5.—Summary statistics by time period and region for the southeast U.S. Atlantic headboat fishery.

Year	Vessels	Mean anglers	Mean maximum anglers	Mean species reported	Peak month	Mean trips per year
Carolinas						
1973–1983	58	32.3	61.0	5.5	July	2,139
1984–1991	42	39.7	68.6	6.3	July	2,318
1992–2000	57	34.0	59.4	6.7	June	2,575
2001–2009	52	32.8	54.1	6.1	July	2,455
2010–2013	34	31.1	52.5	5.0	July	3,057
Georgia–North Florida						
1973–1983	25	30.5	57.0	6.6	July	911
1984–1991	20	31.5	56.1	7.7	June	1,370
1992–2000	15	25.8	61.8	6.5	June	1,150
2001–2009	16	26.3	45.2	6.7	May	1,148
2010–2013	12	26.7	46.0	5.1	June	995
South Florida						
1973–1983	70	20.3	44.3	5.9	July	3,398
1984–1991	60	22.4	50.9	6.8	June	8,148
1992–2000	75	20.0	49.7	5.0	June	6,698
2001–2009	52	21.4	50.4	5.4	June	3,374
2010–2013	42	21.2	50.3	4.8	June	7,659

matched trips. Because the BP's are a sample of the total catch on a trip, the number of fish measured in the BP should always be equal to or less than the number of fish reported in the CR. Port agents tend to measure up to 10 fish per species and it's unlikely that the BP would contain more fish than the CR for the more common species. If the number of fish measured in the BP is greater than the number reported caught in the CR, then an error necessarily exists in either the CR-reported catch or in the BP data.

We assumed accuracy in the BP data because they are collected by trained scientists and in recent time periods subjected to quality control procedures, implying that any discrepancy was due to error (under-reporting) in the CR. All comparisons of CR's and BP's were conducted at the level of individual vessels. It is possible that underreporting could have occurred at the level of individual trips for specific vessels that would not necessarily have been identified with this approach.

We compared temporal trends in the CR-reported landings for each species with trends in the number of fish measured on the matched BP's. We assessed the degree of correlation between the species-specific number of fish measured on the BP's to those reported caught on the CR's using Spearman's rank correlation analysis. Assuming the sampling fraction and reporting accuracy were constant over time, we would expect high correlation. Discrepancies between the BP and CR trends may be indicative of misreporting of catch.

Results

The trend in estimated annual number of headboat trips throughout the SEUS has declined from about 24,000 to 15,000 between 1980 and 2013 (Table 4). Substantial differences in the numbers of reported and estimated trips between 1980 and 2008 are due to an average compliance rate of 50%, which was primarily driven by very low compliance in southeast Florida. A steady decline in estimated headboat trips occurred from 1992 (22,377 trips) until 2008 (11,627 trips) but since 2008, the number of trips has increased ~ 25% and compliance has reached ~95%.

Logbook-reported data, by region and time block are summarized in Table 5. A few of the species reported most frequently in the Carolinas were black sea bass, vermilion snapper, gray triggerfish, tomtate, red porgy, and white grunt (Table 2). Two species of note, Atlantic sharpnose shark and spottail pinfish, occurred on 0% and 12% of CR's in the early time period, but 36% and 29% during 2010 to 2013. The species reported most frequently in Georgia and northeast Florida were black sea bass, vermilion snapper, gray triggerfish, red snapper, and cobia. The species reported most frequently in southeast Florida were yellowtail snapper, mutton snapper, gray snapper, white grunt and gray triggerfish. A noticeable shift in species reported through time exists among regions.

The headboat vessels in southeast Florida contribute 60% of the total number of headboat fishing trips in the SEUS, while vessels in the Carolinas contribute 27% and vessels in Georgia-northeast Florida contribute 13%. In the Carolinas and Georgia-northeast Florida the majority of these reported trips were full day trips (54% and 70%, respectively), while in southeast Florida most were half-day trips (74%).

The median number of fish (pooled across species) measured per trip by year and by area in DISP sampling is shown in Figure 3. The median number of fish measured per trip ranged from 9 to 47 and was typically higher in the Carolinas (range: 15–47) than

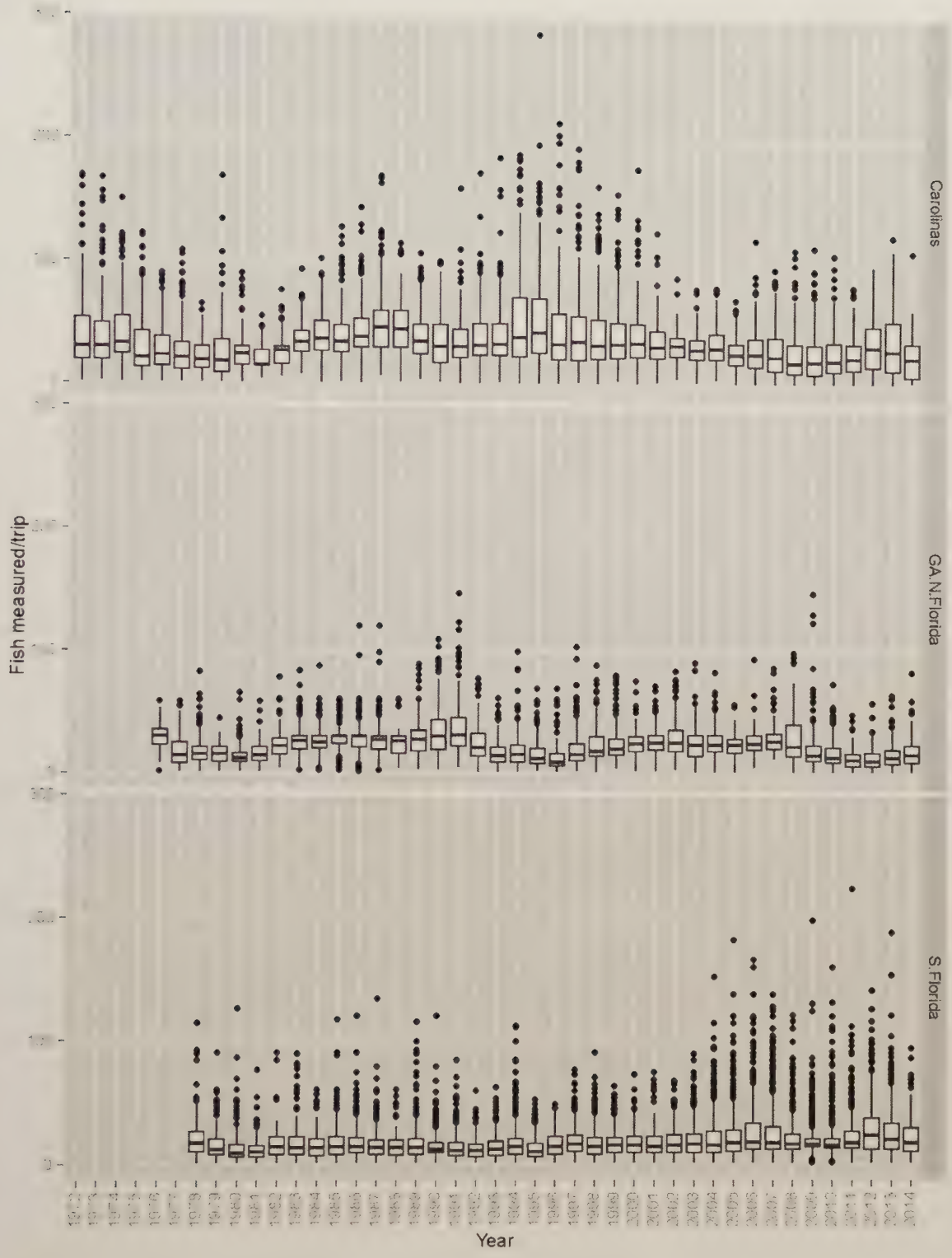

Figure 3.—Box plots representing the total number of fish (pooled across species) measured per trip by region and year. The box is the interquartile range, the horizontal line indicates the median, and the dots indicate outliers outside the 25th and 75th percentiles while the vertical lines represent 1.5 times the interquartile range.

in Georgia-northeast Florida (range: 10–31) and southeast Florida (range: 9–23). Overall, the total number of fish measured was relatively consistent over time within each region.

The median number of species sampled across all trips ranged from 3 to 8 and was slightly higher in the 1980's and 1990's in the Carolinas compared to the other two regions (Fig. 4). The maximum number of species sampled also appeared to be high in the 1980's and 1990's, particularly in the Carolinas and in Georgia-northeast Florida, while the maximum number of species sampled was also high throughout the 2000's in southeast Florida. The median number of fish of each species sampled across all trips was stable among areas suggesting that SRHS sampling protocols were implemented consistently during periods of possible staff turnover and changes in the fishery (Fig. 5).

The CR "trip" field identifies trip length categorically (Fig. 6, 7). For analyses, CR trip lengths were merged into full- and half-day categories where half-day was defined as any duration less than full-day. Of the half-day trips in the Carolinas and Georgia-northeast Florida, there were rarely more than two trips in a day, while three trips per day was fairly common in southeast Florida.

Validation analyses were limited to the full-day trips for matched BP and CR records. There was a predominance of full-day trips in the Carolinas and Georgia-northeast Florida. Although the overall (across all regions) number of matched trips was relatively small, it was constant through time and across vessels.

Seventy-four vessels (11.6% of the 637 vessel-area-time block combinations in the SRHS database) were flagged by at least one metric with an absolute modified z-score greater than 3.5 (Table 6). Seven species-specific metrics and three NMDS metrics flagged vessels. Of the 74 vessels flagged by at least one metric, 15% (n=11) occurred in the southeast Florida region during 1972–83. Of the 74 vessels flagged and individual trips investigated, the findings were often explained by low sample sizes, inshore species assemblage influencing the NMDS results, or species metrics with above-average catches.

BP's represent a subsample of the CR's and therefore should always have fewer fish. If BP's have more fish than CR's, this indicates that not all fish were reported in the CR's. Across regions, underreporting (fewer fish reported on CR's than on matched BP's) was evident for only a small proportion of vessels. When underreporting was observed, the number of "missed fish" was very small across years for all regions (Fig. 8–10).

Species such as red snapper and gray triggerfish had relatively few and small discrepancies between the BP's and CR's (Fig. 11, 12). For other commonly encountered species the number of fish missed (underreported) on the CR's (based on comparison to the BP's) was also a very small proportion of the reported catch, and those instances occurred sporadically across the time series and the three regions.

For rarer species such as littlehead porgy, *Calamus proridens*; and ocean triggerfish, *Canthidermis sufflamen,* the proportion of missed fish in the Carolinas and Georgia-northeast Florida was relatively low and similar to that for well-sampled species in those areas (Fig. 13, 14). However, in southeast Florida there tended to be more missed fish for less common species or species that were difficult to identify to species (e.g., porgy).

Species-specific correlations between reported landings and numbers sampled on the BP's were typically highest in regions where the focal species occurs in highest abundance (and is therefore most commonly caught). Species-specific time series of landings in the CR's correlated positively with the number sampled in the BP's, although correlations tended to be weaker in southeast Florida than in the Carolinas and Georgia-northeast Florida (Fig. 15).

Discussion

We believe this analysis of potential misreporting supports the conclusion that the SRHS data are largely accurate and unbiased, but remain unvalidated. The detection of outliers and patterns in the computed metrics was dependent to some extent on the choice of spatial and temporal strata. The methods used here would not detect misreported data that were reasonably consistent with accurate self-reported data. However, this type of misreporting would likely have negligible effects on resulting data products (e.g., landings and indices of abundance), which rely on the assumption that the central tendencies are unbiased. Our outlier analysis was designed to detect potentially misreported data that are inconsistent with the bulk of the database. For this approach, the identification of outliers was based on the modified z-score methodology Iglewicz and Hoaglin (1993) recommended, a threshold value of 3.5 (adopted here), while Hammer et al. (2010) used a threshold of 3 to delineate outliers. Various thresholds lower than 3.5 (3.25, 3, 2.75) were explored here and, as expected, resulted in increases in flagged vessels. These vessels and the associated trips that were examined, indicate that vessels with a modified z-score less than 3.5 were trips in the outer edge of the median, but were not considered extreme.

The analyses focusing on BP data were limited to a subsample of trips for which the data could be matched to logbook (CR) data. It was only possible to match BP and CR data for full-day trips (i.e., trips on days when the vessel made only one trip, regardless of trip type). This resulted in a subsample of trips in the Carolinas and in Georgia-northeast Florida because full-day trips are common in these regions, where more time is needed to reach desired fishing grounds further offshore. In contrast, the matched trips were only a small proportion of the total trips in southeast Florida, where there was a predominance of partial-day trips due to the region's close proximity to deeper waters.

A spatial shift from full-day trips in the north to predominately partial-day trips in the south may help explain

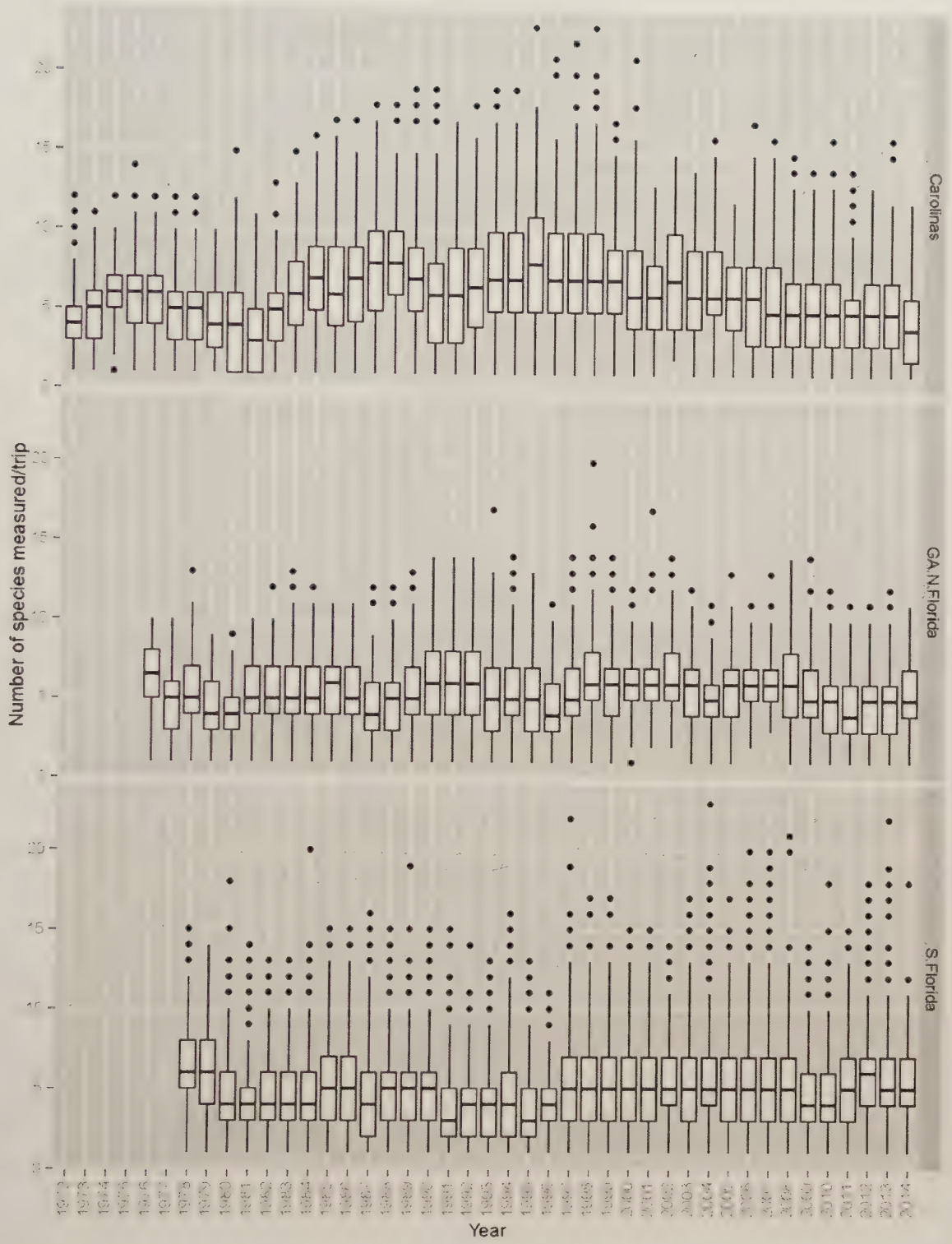

Figure 4.—Box plots representing the median number of species measured per trip by region and year. The box is the interquartile range, the horizontal line indicates the median, and the dots indicate outliers outside the 25th and 75th percentiles while the vertical lines represent 1.5 times the interquartile range.

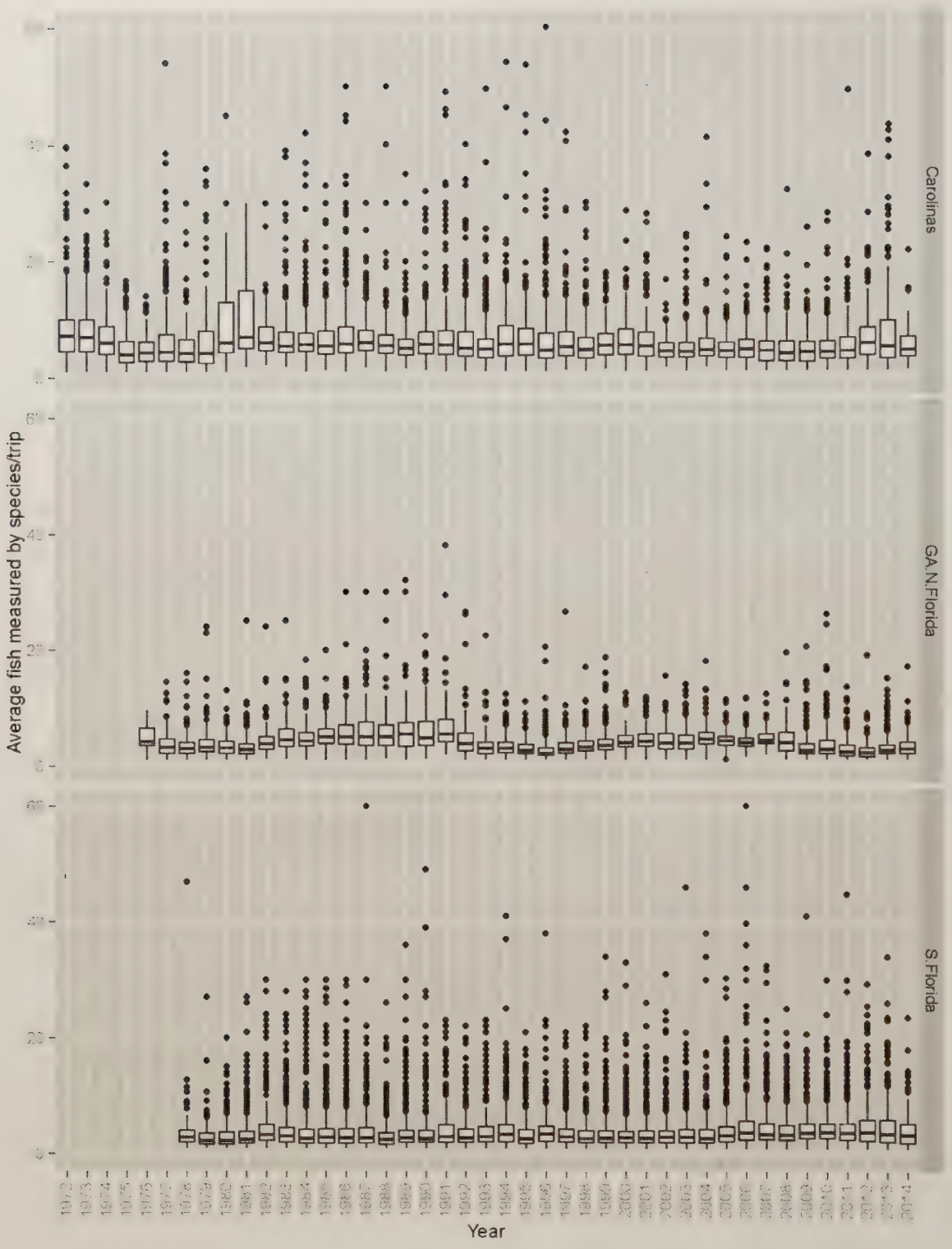

Figure 5.—Box plots representing the median number of fish measured per trip by region and year. The box is the interquartile range, the horizontal line indicates the median, and the dots indicate outliers outside the 25th and 75th percentiles while the vertical lines represent 1.5 times the interquartile range.

Table 6.—Flagged vessels by modified z-score. Column designations are: Region (1=Carolinas, 2=Ga-nFL, 3=sFL), n.trips=Number of trips, yts.m=yellowtail snapper mean catch, vs.m=vermilion snapper mean catch, tom.m=tomtate mean catch, ms.m=mutton snapper mean catch, wg.m=white grunt mean catch, kwporgy.m=key west porgy mean catch, sdprch.v=sand perch variance, z_sp_25=NMDS presence/absence top 25 species, z_sp_all=NMDS presence/absence all species, z_cpue_all=NMDS catch rate all species. Bold highlights the values that are greater than 3.5 (significant outliers).

Year	Region	n.trips	yts.m	vs.m	tom.m	ms.m	wg.m	kwporgy.m	sdprch.v	z_sp_25	z_sp_all	z_cpue_all
1972–1983	1	1								**4.5**	2.5	2.2
1972–1983	1	1					0.1			**4.6**	2.7	1.9
1972–1983	2	1		0.1						**4.2**	2.5	1.2
1972–1983	3	1	1.1		1.1	0.5		1.5		**4.1**	3.1	2.0
1972–1983	3	1			0.1	-0.2				**4.8**	2.8	1.3
1972–1983	3	1					0.3			**6.3**	**4.0**	2.5
1972–1983	3	1		0.7						**5.5**	**4.1**	1.5
1992–2000	3	1	-1.5			-0.6				**5.9**	**6.8**	3.4
1972–1983	2	2								**6.3**	**4.0**	2.4
1984–1991	3	2				0.9				**7.0**	**4.0**	2.5
1992–2000	1	2								**5.1**	**4.4**	1.9
1984–1991	3	3		0.7	0.3					**4.6**	3.0	1.8
2001–2009	1	3								**7.1**	**5.6**	3.2
2001–2009	2	3		0.2						**7.9**	**5.0**	2.7
2010–2013	2	3		1.2						**304.1**	**4.1**	**4.8**
2010–2013	2	3				0.2				**303.9**	**4.5**	**3.5**
1984–1991	3	4	-0.3			-0.4				**3.9**	1.2	1.6
1984–1991	3	5	0.2			1.2				**4.0**	1.9	1.0
1984–1991	3	6	0.1		0.2	0.2	0.0			**3.6**	2.2	1.6
1972–1983	3	7				0.2				**5.7**	3.3	2.1
1972–1983	3	7								**8.2**	**4.8**	3.1
1984–1991	3	7	0.9		-1.0	0.4	-1.0			**4.0**	2.5	1.6
1992–2000	2	7			0.4					**5.6**	**7.3**	3.4
1992–2000	3	7	0.3							**6.2**	**7.0**	2.1
2010–2013	2	7				-0.3				**304.7**	**4.1**	3.0
1972–1983	3	8		0.5			-0.4			**4.0**	1.7	1.7
2010–2013	2	8								**658.8**	**10.3**	**4.9**
1992–2000	1	9								**5.3**	**4.0**	1.8
2001–2009	3	9	0.6			0.3	-0.8			**6.0**	**4.6**	0.9
2001–2009	3	9	0.1			-0.4	0.2	0.7		**4.2**	**5.1**	1.0
1972–1983	3	10		0.1		-0.1		0.0		**5.7**	3.3	1.9
2010–2013	3	10	0.2	0.8		0.4				**7.2**	2.8	1.3
2001–2009	2	12					-0.7			**7.6**	3.1	1.8
2010–2013	3	12	-1.1			-0.7				**11.9**	**6.1**	**4.7**
1984–1991	2	14		1.6	-0.8					**4.8**	1.4	1.6
2001–2009	1	15								**3.5**	2.2	2.4
1984–1991	2	16		-0.5	0.0				0.3	**5.1**	1.6	0.8
1992–2000	2	16		0.1	-1.0		-0.1			**3.9**	**5.0**	3.2
2001–2009	2	16		0.4			-0.8			**4.1**	3.2	1.0
1984–1991	1	17							-0.4	**6.5**	3.2	2.2
1984–1991	3	25	0.3			-0.7	-1.5	-0.3		**3.6**	2.0	0.4
1972–1983	3	26			0.0		0.1	-0.6		**4.6**	3.4	1.0
1972–1983	3	33	-0.7			-0.9	-0.3	0.2		**3.5**	1.4	0.6
2010–2013	2	35			-1.1		0.4			**303.3**	3.0	2.4
2001–2009	1	40								**3.8**	2.6	1.0
1972–1983	1	57								**4.5**	2.5	2.2
2001–2009	1	62								**5.8**	3.4	1.5
1992–2000	1	78								**3.6**	2.5	0.6
1972–1983	2	82		-0.3	0.3			**3.8**		0.3	0.4	-0.7
1992–2000	1	92								**4.9**	3.1	1.0
2010–2013	1	95			-0.7		0.1			**3.7**	3.2	0.9
2010–2013	3	126	-0.2	0.1		0.4				**5.7**	2.1	1.5
2010–2013	1	128		**-4.2**						2.4	2.7	0.2
1984–1991	2	132	0.7	0.5	0.8	0.6	**4.6**	0.4	0.8	-0.4	-0.2	-0.5
2010–2013	1	153								**3.7**	**4.0**	1.2
1992–2000	1	163		0.2		**3.6**	0.6	0.7		0.0	-0.1	-0.4
1984–1991	1	213			-0.7					**4.8**	1.8	0.1
2001–2009	1	263								**3.6**	2.3	0.8
2010–2013	1	272		**-4.6**	-0.6		0.1	-0.5	0.4	-0.4	-0.2	-0.5
1992–2000	2	289		0.6						2.5	**4.0**	1.0
1984–1991	1	298			-1.3					**7.8**	3.0	**3.9**
1992–2000	1	299		1.4						**3.6**	2.6	0.5
1972–1983	3	362	0.3	0.4	0.7	0.1	0.1	0.5	**-5.5**	0.0	0.2	-0.7
1984–1991	2	377	0.1	-0.3	0.2	1.7	**5.0**	0.0	0.6	-0.8	-0.7	-0.5
2010–2013	1	387	**4.6**	-0.6	-0.1		0.0	0.0		0.0	-0.1	-0.6
2010–2013	1	406	**4.6**	-0.5	0.5	2.0	0.2	0.3	0.0	0.0	-0.4	-1.2
2010–2013	1	455					0.0			**5.3**	**5.1**	1.2
1984–1991	2	459	-0.3	0.1	-0.3	-0.4	**3.8**	-0.3	1.6	-0.4	-0.3	-0.2
2010–2013	3	542	0.0			-0.4	0.5	0.3		**4.0**	0.8	0.2
1984–1991	1	823		-2.1	-1.5	**4.6**	-1.0	-1.2	0.0	-0.5	0.3	0.0
2001–2009	1	968	0.7	0.1	1.3	**7.0**	0.4	0.4	1.1	0.0	-0.4	-0.6
2001–2009	2	1,696	0.3	-0.7	-0.7	0.5	0.0	**3.8**		-0.4	-0.6	-0.4
1984–1991	2	2,141	0.0	-0.7	**-3.6**	-0.2		0.0		0.4	-0.1	0.2
1984–1991	1	2,143		-0.3	0.7		-1.6			**6.4**	2.9	0.3

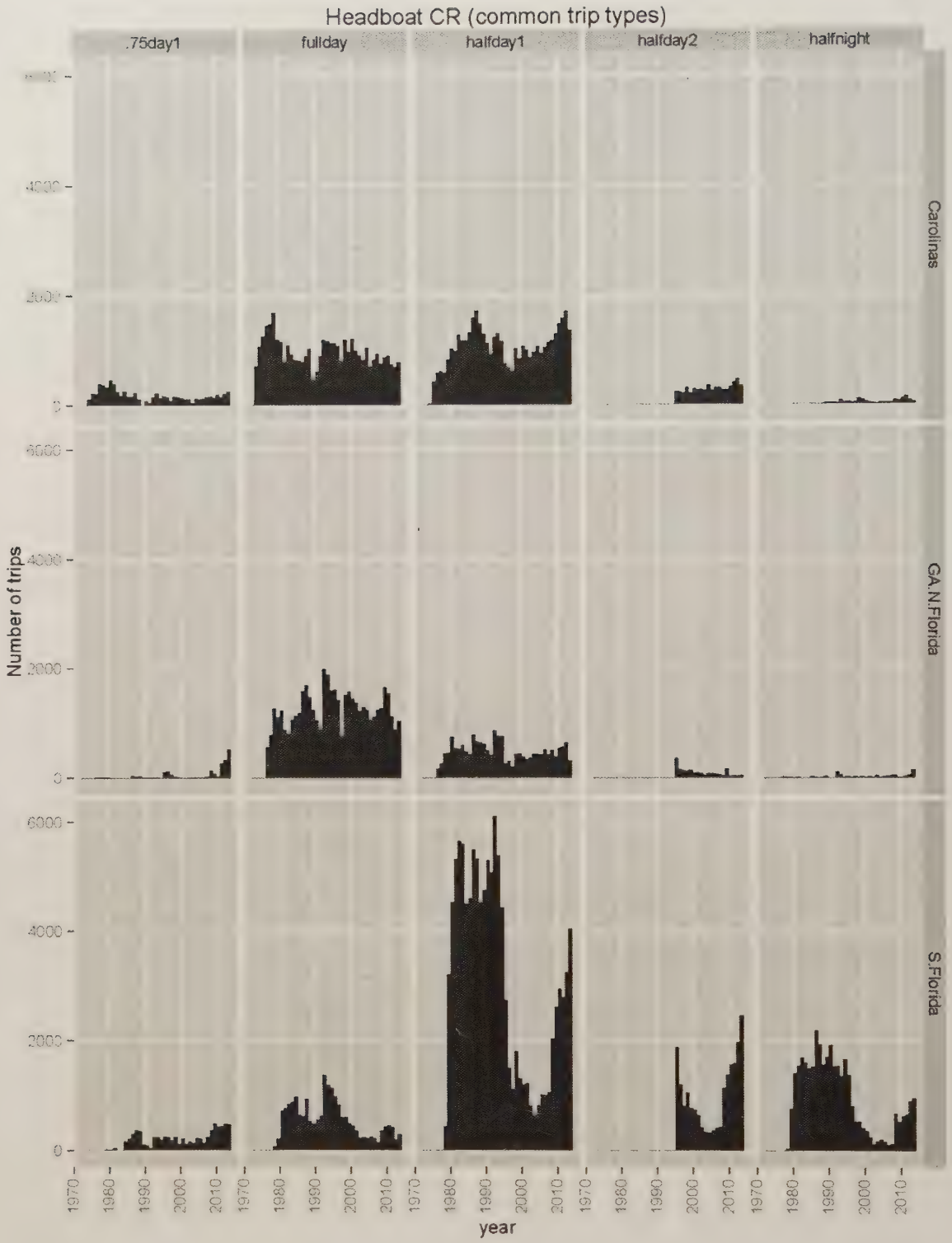

Figure 6.—Number of common trip types in southeast U.S. Atlantic headboat fishery catch records by year and region. "75day1" represents a three-quarter-day trip approximately 6 h in length, "fullday" represents an approximate 8 h trip, "halfday1" represents an approximate 4 h morning trip, "halfday2" represents an approximate 4 h afternoon trip, "halfnight" represents an approximate 4 h night trip.

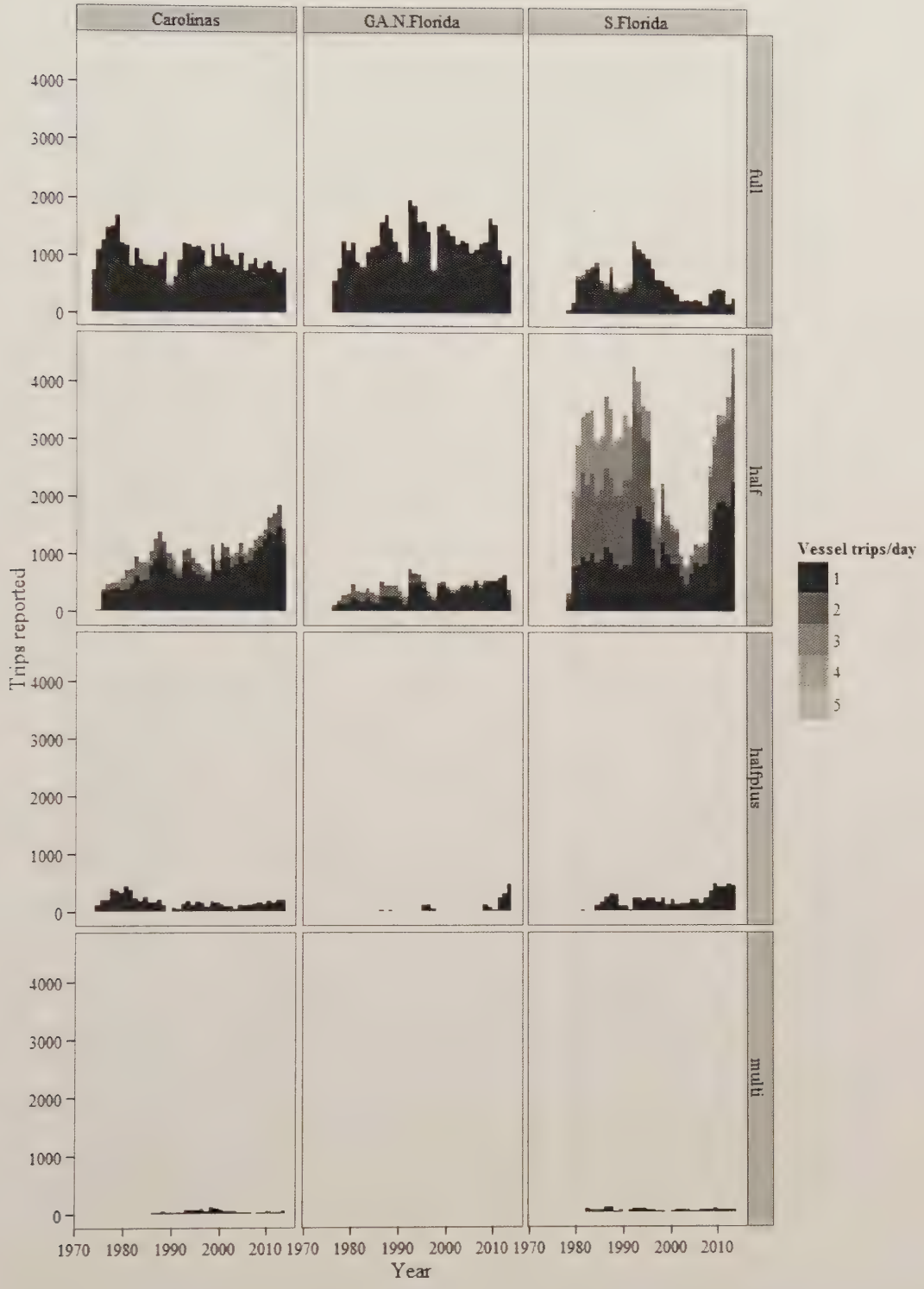

Figure 7.—Number of all trip types in the southeast U.S. Atlantic headboat fishery catch records by year and region. "Full" represents an approximate 8 h trip, "half" represents an approximate 4 h morning trip (dropped afternoon trips), "halfplus" represents a three-quarter-day trip approximately 6 h in length, "multi" represents a trip longer than 8 h.

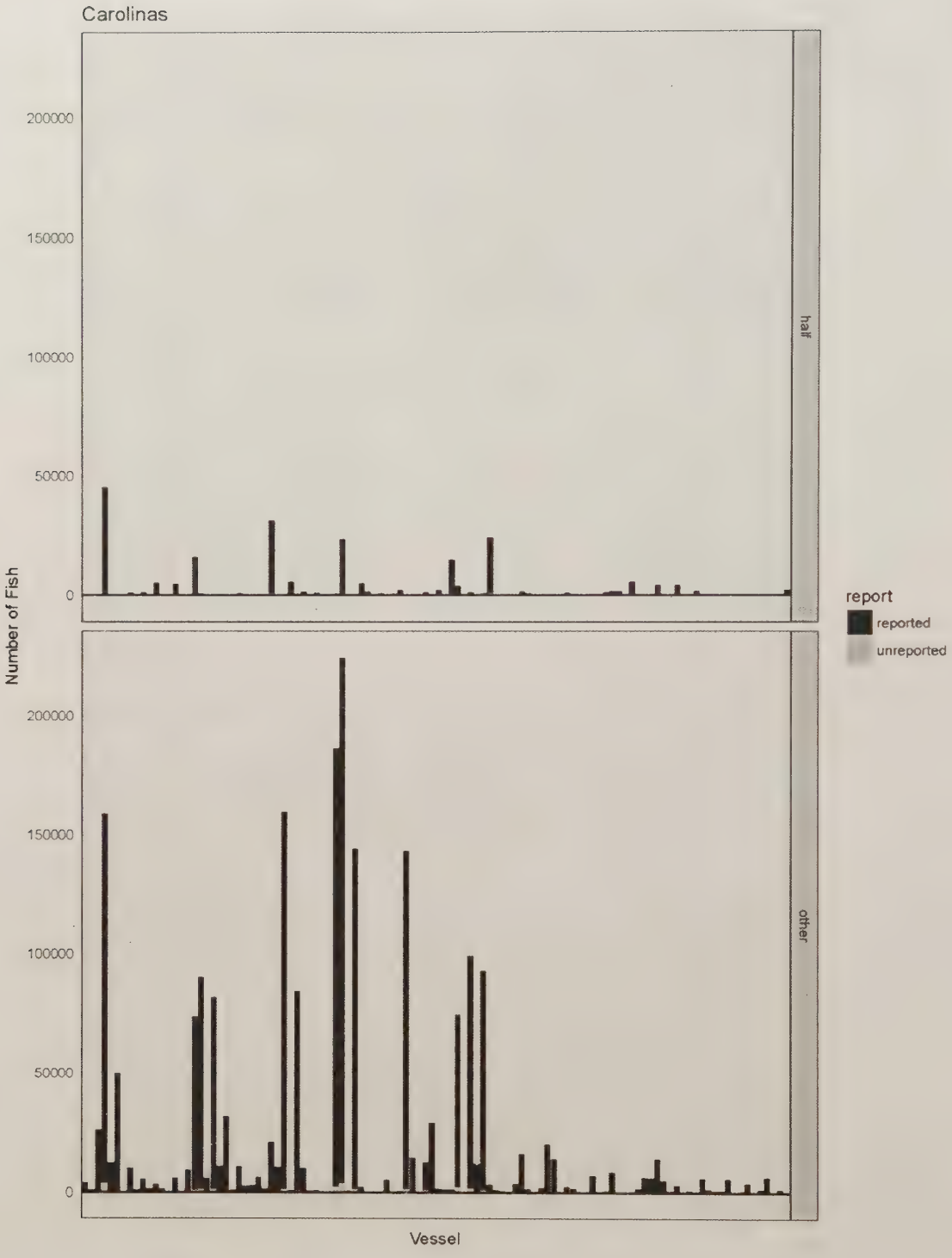

Figure 8.—Number of fish sampled but not reported on the logbook in the Carolinas, by vessel, using matched trips over all years ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

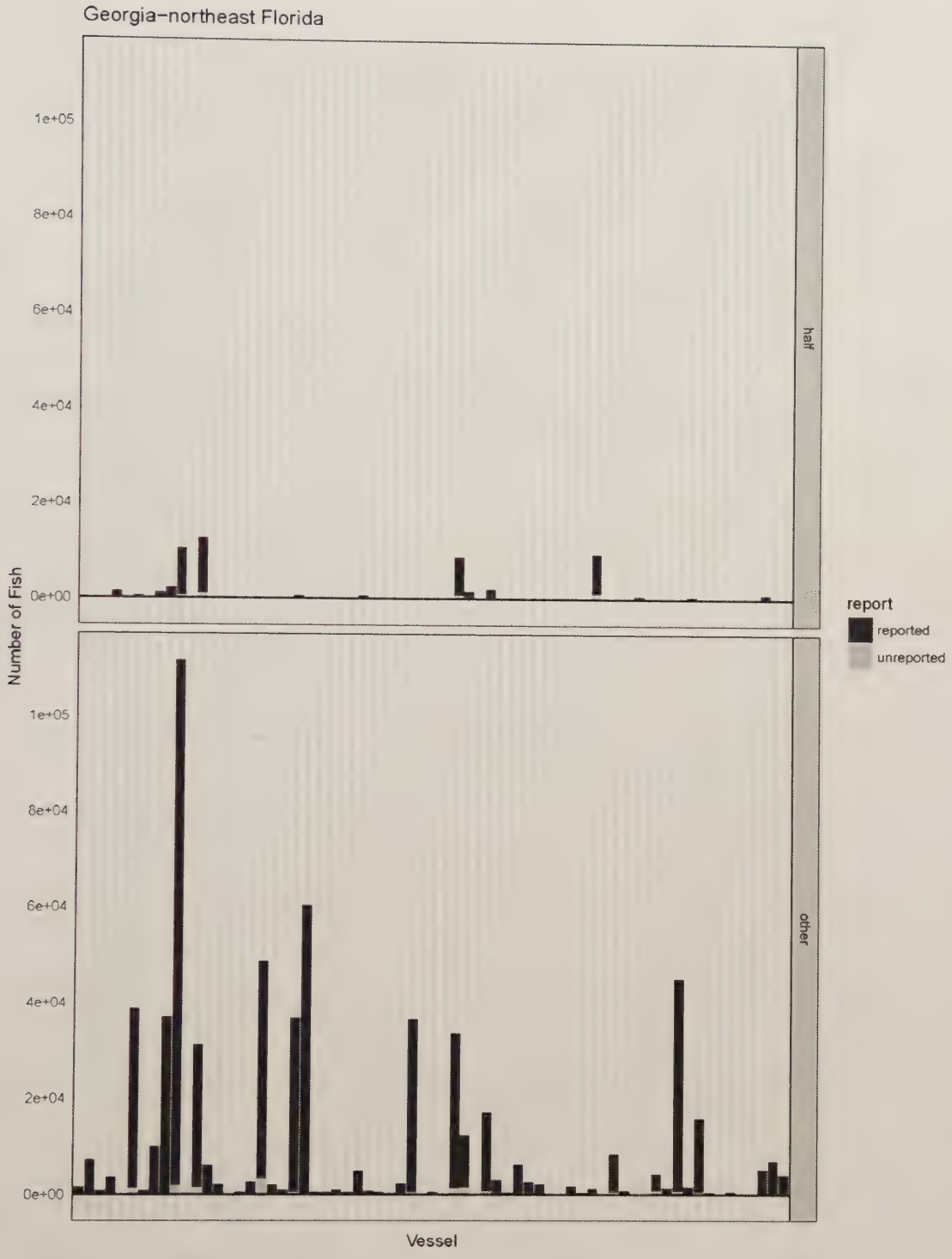

Figure 9.—Number of fish sampled but not reported on the logbook in Georgia-northeast Florida, by vessel, using matched trips over all years ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

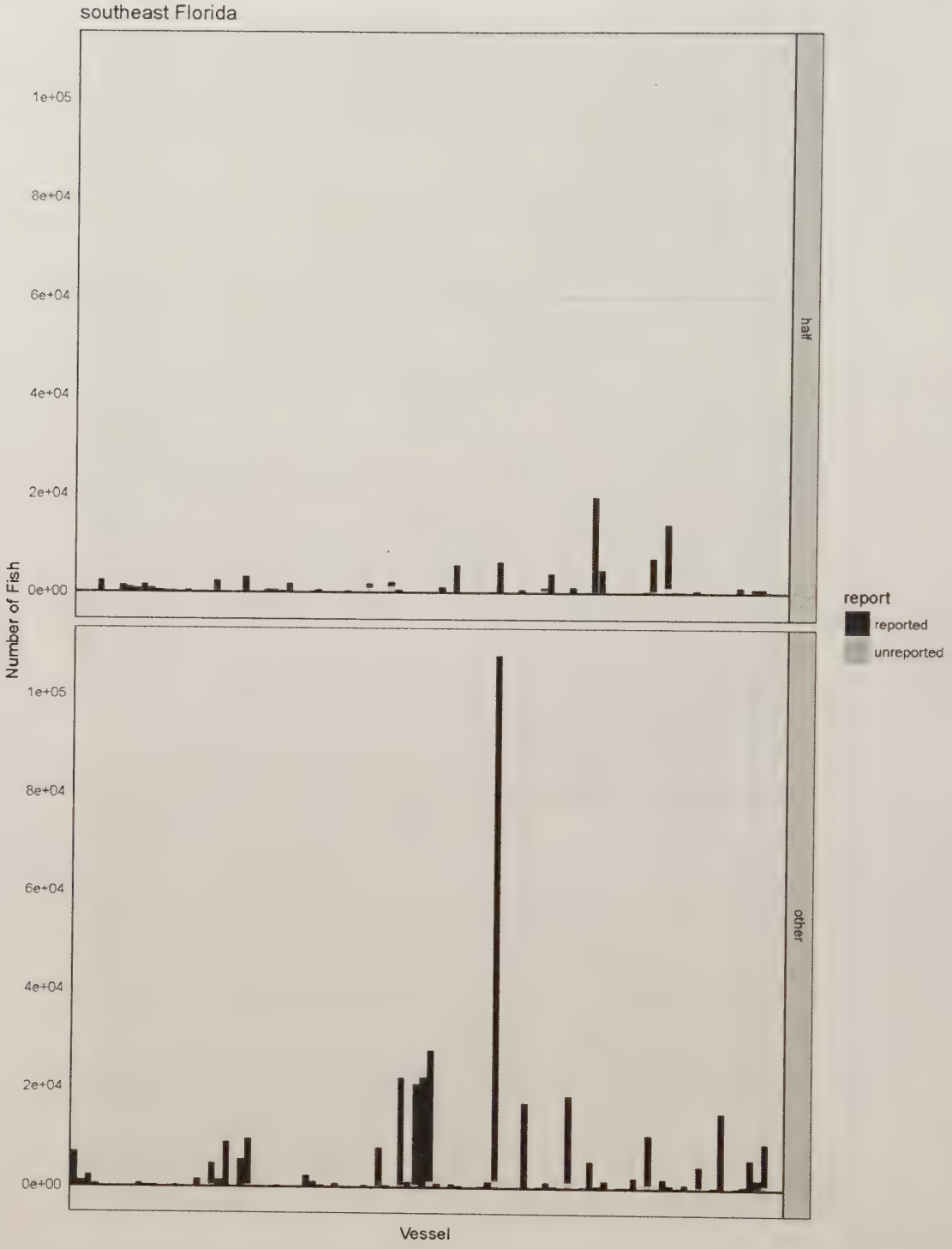

Figure 10.—Number of fish sampled but not reported on the logbook in southeast Florida, by vessel, using matched trips over all years ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

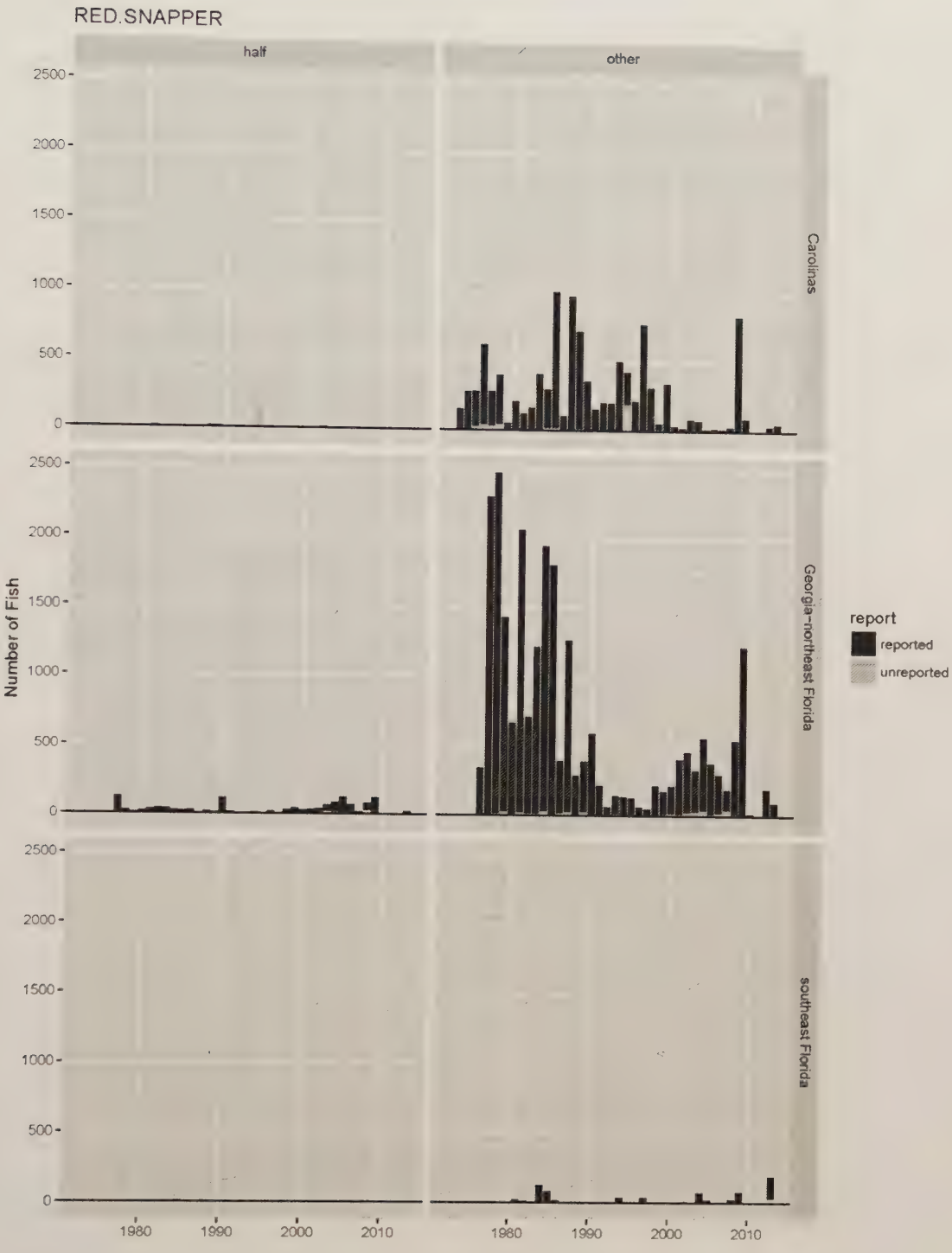

Figure 11.—The number of missed red snapper reported on the logbook by year in each region by all vessels using matched trips ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

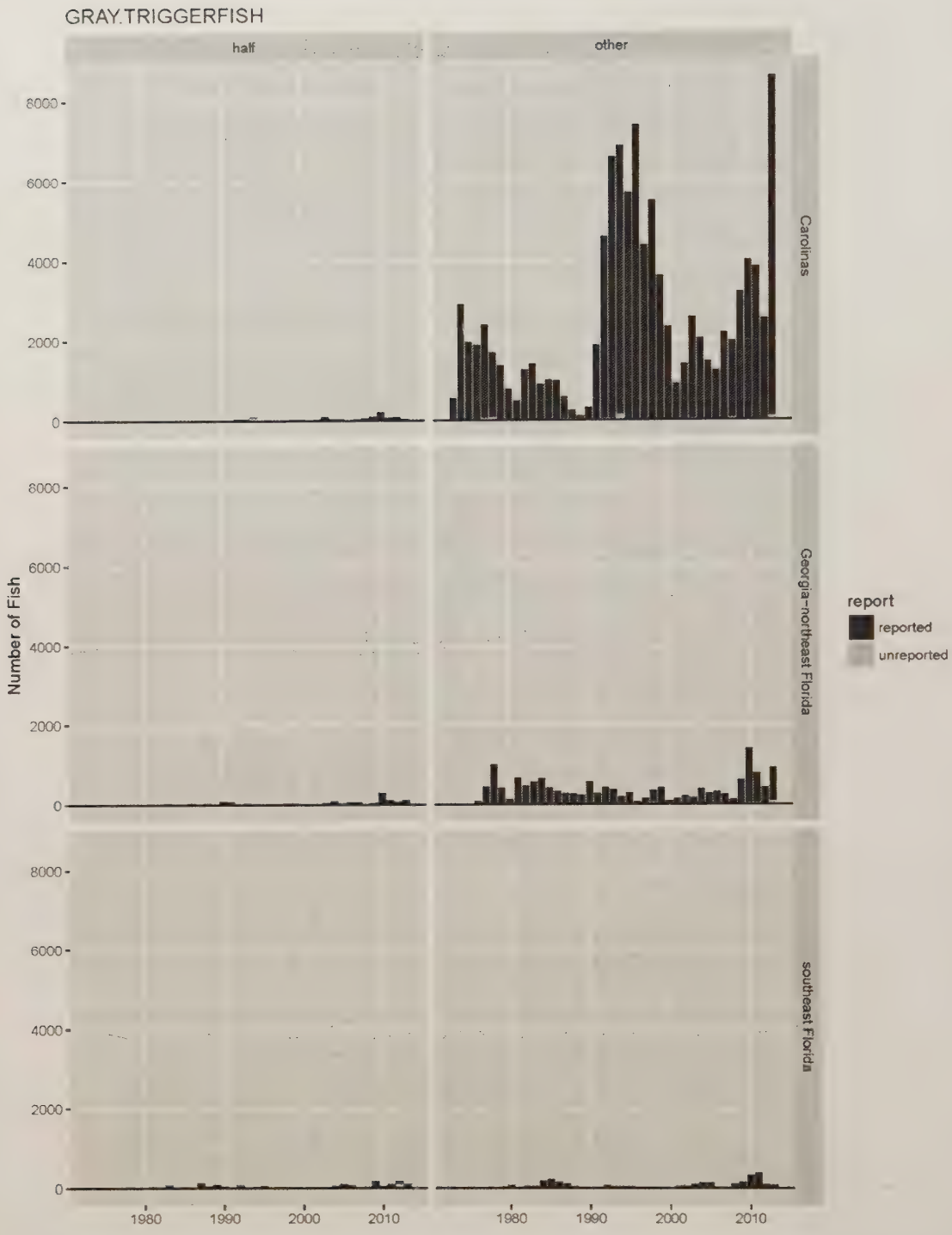

Figure 12.—The number of missed gray triggerfish reported on the logbook by year in each region by all vessels using matched trips ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

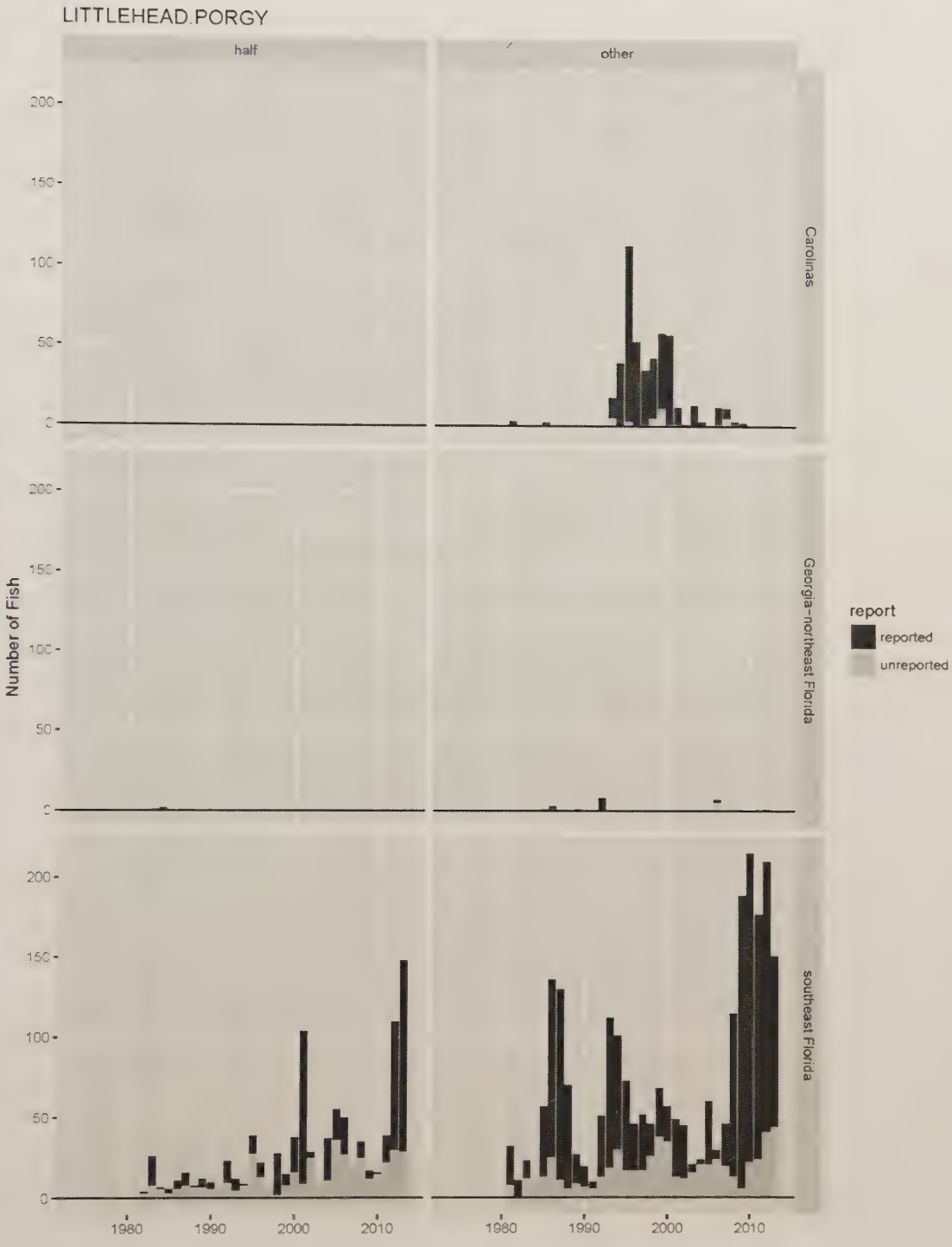

Figure 13. —The number of missed littlehead porgy reported on the logbook by year in each region by all vessels using matched trips ("half" and "other" trips, i.e., all trips other than "half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

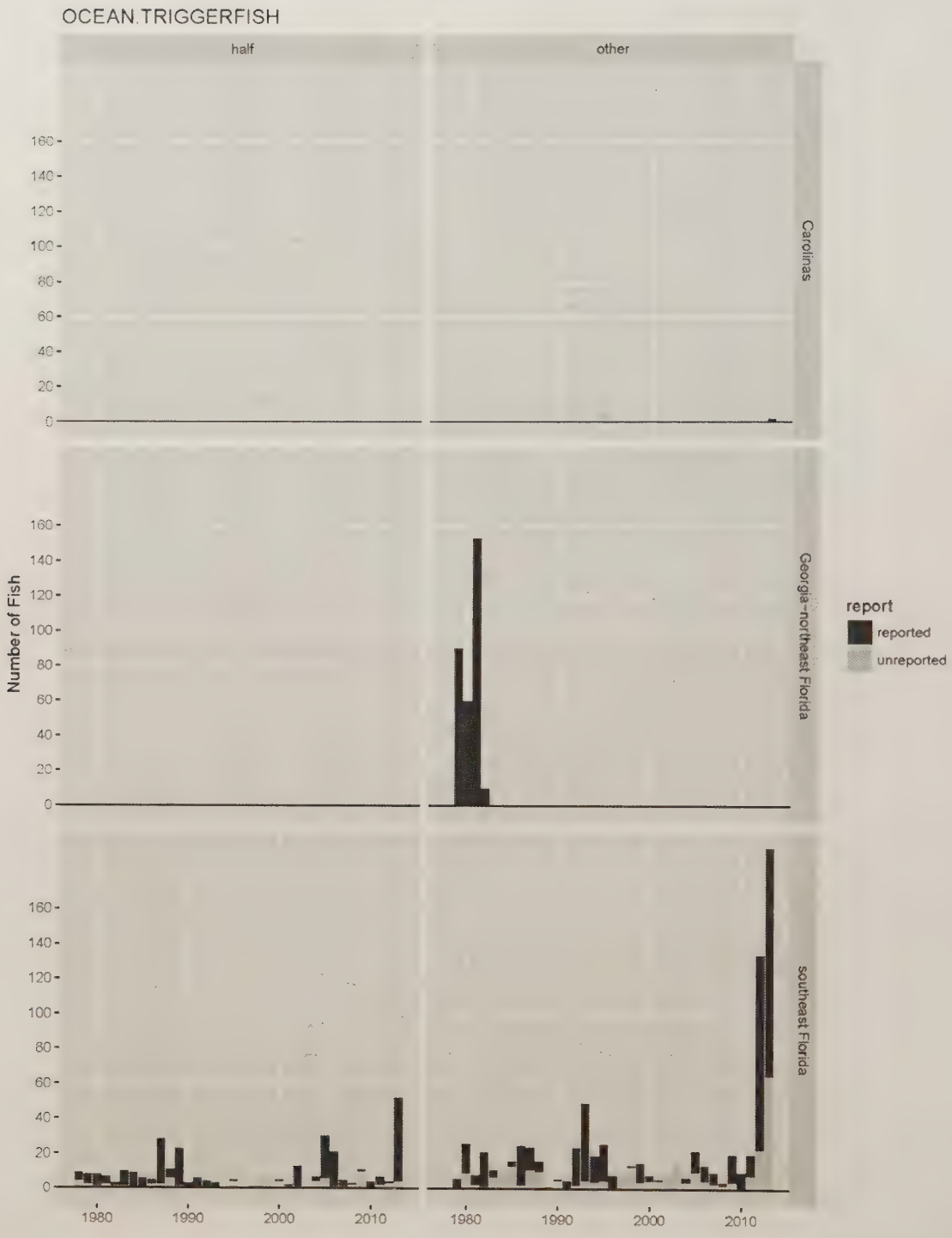

Figure 14. —The number of missed ocean triggerfish reported on the logbook by year in each region by all vessels using matched trips ("half" and "other" trips, i.e., all trips other than"half-day"). The grey bar is the total number of fish reported on CR's for the matched trips. The black bar is the difference between the total number of fish reported on BP's and the total number of fish reported on CR's for the matched trips, and is only shown if that difference is positive. For confidentiality vessels are unidentified.

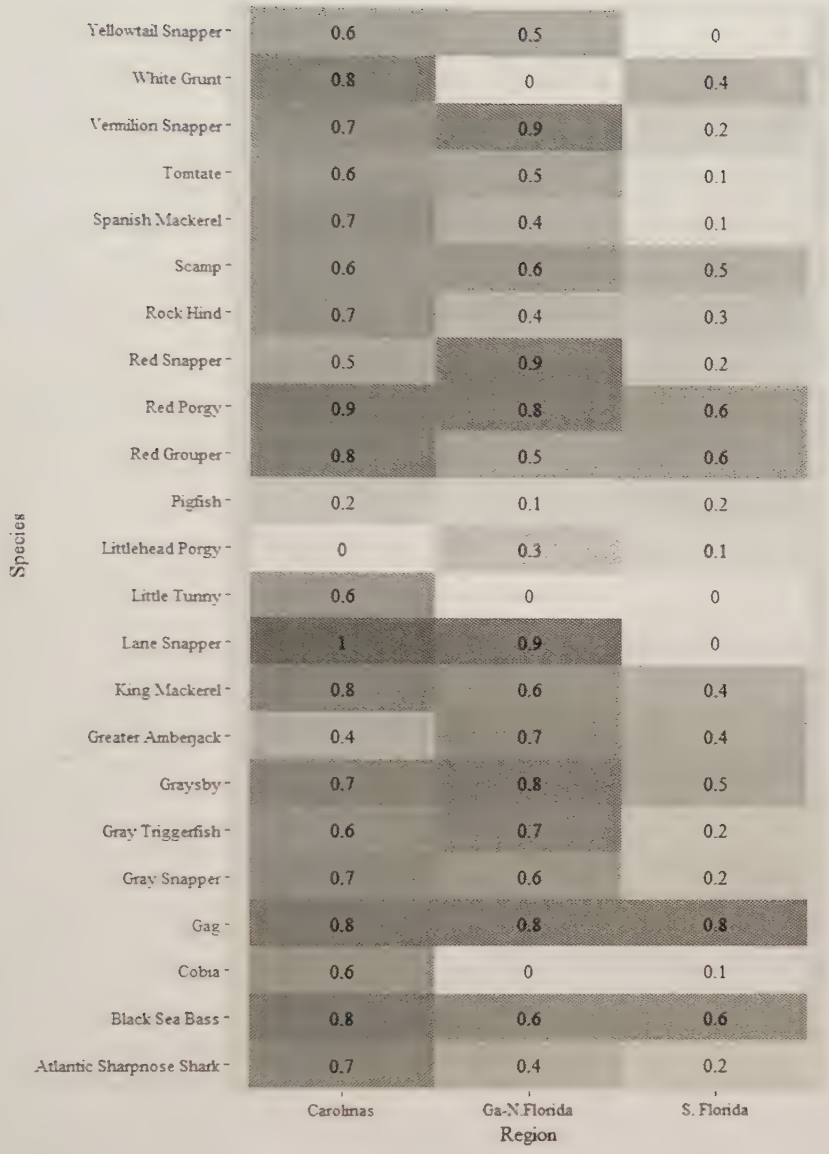
Yellowtail Snapper 0.6 0.5 0
White Grunt 0.8 0 0.4
Vermilion Snapper 0.7 0.9 0.2
Tomtate 0.6 0.5 0.1
Spanish Mackerel 0.7 0.4 0.1
Scamp 0.6 0.6 0.5
Rock Hind 0.7 0.4 0.3
Red Snapper 0.5 0.9 0.2
Red Porgy 0.9 0.8 0.6
Red Grouper 0.8 0.5 0.6
Pigfish 0.2 0.1 0.2
Littlehead Porgy 0 0.3 0.1
Little Tunny 0.6 0 0
Lane Snapper 1 0.9 0
King Mackerel 0.8 0.6 0.4
Greater Amberjack 0.4 0.7 0.4
Graysby 0.7 0.8 0.5
Gray Triggerfish 0.6 0.7 0.2
Gray Snapper 0.7 0.6 0.2
Gag 0.8 0.8 0.8
Cobia 0.6 0 0.1
Black Sea Bass 0.8 0.6 0.6
Atlantic Sharpnose Shark 0.7 0.4 0.2
Species
Carolinas
Ga-N.Florida
S. Florida
Region

Figure 15.—Spearman rank correlation coefficient (rho) between landed (CR's) compared to the number sampled (BP's) by year and region for species in the southeast U.S. Atlantic headboat fishery.

the slight decrease in number of species sampled in southeast Florida due to the decrease in actual fishing time. Additionally, because there are few full-day trips in southeast Florida, it is possible that the single-day trips that do occur are atypical in some way. For example, a vessel might make only one trip in a day if inclement weather or a mechanical issue prevented subsequent trips, both of which could affect fishing success (e.g., landings reported on the logbook report). Thus, results from matched-trip analyses for the southeast Florida region should be interpreted with caution given the relatively small sample sizes and the potential inclusion of atypical trips.

The utility of the analysis may have been limited to some extent by changes over time in protocols that determine the number of individuals of each species that should be measured in BP samples or in consistency in carrying out those protocols. In general, the observed consistency and degree of correlation between CR-reported landings and number of fish sampled on the BP's suggests that the approach used was robust to this potential source of error with the exception of southeast Florida for certain species.

The analytical methods applied in this study to the SRHS data may prove useful for other fishery data, particularly in cases of self-reported data. The results of our analyses support the hypothesis that the SRHS dataset is a consistent, unbiased, and reliable source of information for assessing and managing stocks in the SEUS. Assessments using SRHS data in recent years have been focused on the more common species. In the future, when rare or data-limited species are assessed it will be imperative to understand the nature of these data before proceeding.

Because headboats make short-duration trips, relative to commercial vessels, and because they tend to target habitat rather than specific species, they collectively form a good design to sample the critical areas of the snapper-grouper complex. In addition, the vessels are spread out along the coast to cover the full geographic region of the SEUS. The temporal coverage of the catch-per-unit-effort (CPUE) information is the longest of any dataset in the southeast United States. These properties, particularly the targeting of habitat and not species, make this dataset quite useful for developing indices of abundance for a suite of species. We expect such indices to be less problematic than those generated from most other fishery-dependent CPUE time series in terms of reflecting relative abundance.

Recent improvements (e.g., in terms of data collection protocol, quality control and assurance, database management, electronic reporting, compliance, and inclusion of economic data) ensure that the SRHS will provide useful data for future stock assessments in the SEUS. These systematic changes provide scientists and managers with timely access to reliable data, resulting

in improved fishery management advice for the snapper-grouper complex.

Acknowledgments

We thank the many headboat crew members and NMFS port agents for their efforts in providing data to this project throughout the many years, as well as Rusty Hudson for providing the historical image illustrating a headboat vessel in the SEUS.

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Appendix 1.—List of species present on Headboat Survey Trip Report for each form change from 1973 to 2005.

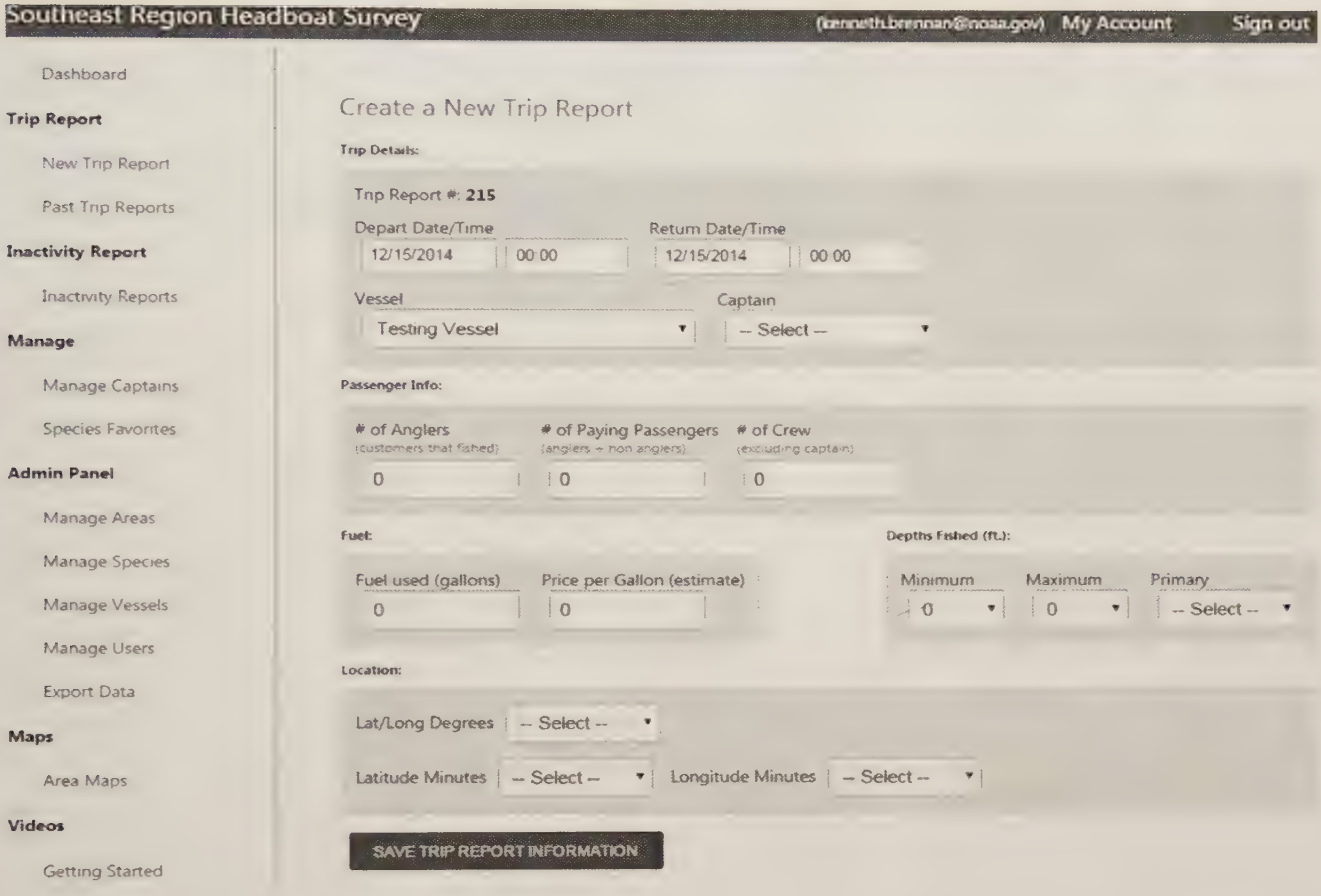
Species	Form 1	Form 2	Form 3	Form 4 (NC/SC)	Form 5 (GA/FL)	Form 6 (NC/SC)	Form 7 (GA/FL)	Form 8 (NC/SC)	Form 9 (GA/FL)	Form 10 (NC/SC)	Form 11 (GA/FL)	Form 12 (NC/SC)	Form 13 (GA/FL)	Form 14 15, 16
Number of species	24	26	30	35	32	35	31	36	67	62	71	65	74	69
Years used ('YY-'YY)	73–74	74–75	75–77	76–77	76–77	77–83	77–79	80–81	80–83	84–86	84–86	86–91	89–91	92–04
Strawberry grouper (Kitty Mitchell)	X	X	X	X	X	X	X	X	X	X	X	X	X	
Warsaw grouper	X	X	X	X	X	X		X		X		X		X
Red grouper	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gag	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Scamp	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Black grouper	X	X	X	X	X	X	X	X	X	X	X	X	X	
Yellowfin grouper	X	X	X	X		X		X	X	X	X	X	X	X
Snowy grouper	X	X	X	X		X		X		X		X		X
Other groupers	X	X	X	X		X		X		X		X		
Red snapper	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Yelloweye snapper	X	X		X		X		X		X		X		X
Vermillion snapper	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Yellowtail snapper	X				X		X		X		X		X	
Other snapper	X	X	X	X		X		X		X		X		
White grunt (Margate)	X	X	X	X		X		X	X	X	X	X	X	X
Other grunts	X	X	X	X	X	X	X	X	X	X	X	X	X	
Red porgy (silver snapper)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other porgies	X	X	X	X	X	X	X	X	X	X	X	X	X	
Tilefish	X	X	X	X		X		X		X		X		
Amberjack	X		X	X	X	X	X	X	X	X	X	X	X	X
Triggerfish	X	X	X	X	X	X	X	X	X	X	X	X	X	
Dolphin	X									X	X	X	X	X
Others	X	X	X	X		X		X		X		X		
Boxes of Sea Bass	X	X	X	X	X									
Rock hind		X	X	X	X	X	X	X	X	X	X	X	X	X
Red hind		X	X	X	X	X	X	X	X	X	X	X	X	X
Tomtate		X	X	X	X	X	X	X	X	X	X	X	X	X
Knobbed porgy (Key West)		X	X	X	X	X	X	X	X	X	X	X	X	X
Other porgies (spot tail bream, scup, etc.)		X	X	X		X		X		X		X		
Bream (spot-tail porgy)			X	X	X	X	X	X	X	X	X	X	X	X
Scup (northern porgy)			X	X		X		X		X		X		X
Whitebone porgy (chocolate porgy)			X	X	X	X	X	X	X	X	X	X	X	X
Squirrelfish			X	X	X	X	X	X	X	X	X	X	X	X
Yellowedge grouper				X		X		X		X		X		
Other groupers (marbled, yellowfin)				X		X		X		X		X		
Other snappers (mutton, etc.)				X		X		X		X		X		
Longspine porgy				X	X	X	X	X	X	X	X	X	X	
Nassau grouper					X		X		X		X		X	
Other grouper (chocolate, etc.)					X		X							
Gray snapper					X		X		X		X		X	X
Lane snapper					X		X		X		X		X	X
Mutton snapper					X		X		X		X		X	X
Other snappers (cubera, schoolmaster, silk)					X		X							
Porkfish					X		X		X		X		X	
Amberina					X		X		X		X		X	
Angelfish					X		X		X		X		X	X
Pounds of Black Sea Bass						X	X	X	X	X	X	X	X	
Almaco jack								X	X	X	X	X	X	X
Graysby									X	X	X	X	X	X
Coney									X	X	X	X	X	
Yellowmouth grouper									X	X	X	X	X	X
Yellowfin chocolate (yellowedge)									X		X		X	
Jewfish									X		X		X	
Sailor's choice									X		X		X	
Black margate									X		X		X	
French grunt									X		X		X	
Bluestripe grunt									X		X		X	X
Littlehead porgy									X		X	X	X	X
Saucereye porgy									X		X		X	
Sheepshead porgy									X	X	X	X	X	
Jolthead porgy									X		X		X	X
Blackfin snapper									X	X	X	X	X	X
Cubera snapper									X		X		X	X
Schoolmaster snapper									X		X		X	
Silk snapper									X		X		X	X
Black snapper									X		X		X	
Queen triggerfish									X	X	X	X	X	X
Gray triggerfish									X	X	X	X	X	X
Ocean triggerfish									X		X		X	
Gray tilefish (blueline)									X	X	X	X	X	X
Sand tilefish (sandeel)									X	X	X	X	X	X
African pompano									X	X	X	X	X	X
Blue runner									X	X	X	X	X	X

Appendix 1.—*Continued*

Appendix 1.—Continued

Species	Form 1	Form 2	Form 3	Form 4 (NC/SC)	Form 5 (GA/FL)	Form 6 (NC/SC)	Form 7 (GA/FL)	Form 8 (NC/SC)	Form 9 (GA/FL)	Form 10 (NC/SC)	Form 11 (GA/FL)	Form 12 (NC/SC)	Form 13 (GA/FL)	Form 14 15, 16
Number of species	24	26	30	35	32	35	31	36	67	62	71	65	74	69
Years used ('YY-'YY)	73–74	74–75	75–77	76–77	76–77	77–83	77–79	80–81	80–83	84–86	84–86	86–91	89–91	92–04
Rainbow runner									X		X		X	X
King mackerel									X	X	X	X	X	X
Spanish mackerel									X	X	X	X	X	X
Cero									X	X	X	X	X	
Bluefish									X	X	X	X	X	X
Bigeye (toro)									X	X	X	X	X	X
Bonito									X	X	X	X	X	X
Barracuda									X	X	X	X	X	X
Cobia									X	X	X	X	X	X
Marbled grouper										X		X		
Dog snapper											X		X	
Hogfish (hog snapper)										X	X	X	X	X
Pigfish										X		X		
Spadefish										X	X	X	X	X
Sand perch										X		X	X	X
Wahoo										X		X		
Bank sea bass												X	X	X
Spottail pinfish												X	X	X
Black sea bass (# and weight)														X
Pinfish														X
Sharpnose shark														X
Sandbar shark														X
Blacktip shark														X
Smooth dogfish														X
Nurse shark														X
Dusky shark														X
Remora														X
Banded rudderfish														X
Yellowfin tuna														X
Short bigeye														X
Spotted soapfish														X
Tattler														X
Inshore lizardfish														X

Appendix 2.—Southeast Region Headboat Survey eLog web based portal.



Lessons on Marine Protected Area Management in Northern Boreal Regions from the United States and Norway

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Introduction

Marine protected areas (MPA's) can be considered a tool for ecosystem-based marine spatial planning (Katsanevakis et al., 2011; Stelzenmüller et al., 2013) and have been established to meet the goals of biodiversity conservation, sustainable management of marine resources, and marine heritage preservation (Fernandez and Castilla, 2005; Field et al., 2006; Worm et al., 2006; Greenville and Macaulay, 2007; Gleason et al., 2010; Grafton et al., 2011; Hansen et al., 2011; Rice et al., 2012). MPA's can also serve to protect habitats from destructive fishing practices (e.g., protection against fishing impacts on coral reefs off Norway), extraction activities, energy production, and petroleum development.

The use of MPA's has necessitated the creation of organizations to monitor and give advice on their designation and use, both within nations (i.e., the National Marine Protected Area Center (NMPAC), part of the National Oceanic and Atmospheric Administration (NOAA) in the United States), and internationally (i.e., the Food and Agricultural Organization (FAO) of the United Nations) (Murawski et al., 2000). For the purposes of this paper, we use the MPA definition formulated in the United States: ". . . area of the marine environment that has been reserved . . . to provide lasting protection for part or all of the natural and cultural resources therein." [1]

From the perspective of many consumptive users of the ecosystem (e.g., fishermen, shipping industry, oil industry), MPA's are often seen as a means to exclude users from accessing valuable areas (Katsanevakis et al., 2011; Thorpe et al., 2011; Abbott and Haynie, 2012; Buhl-Mortensen et al., 2017). Therefore, the decisions regarding area closures are often highly controversial (Thorpe et al., 2011; Rice et al., 2012; Fenner, 2016), and motivate examination of the effectiveness of MPA's relative to other management tools (i.e., reduction in catch levels or fishing effort for sustainably managing fisheries yield).

Within the scientific community, there is ongoing research on the effectiveness of MPA's as management tools for fish species and ecosystems (Trexler and Travis, 2000; Roberts et al., 2005; Sanchirico et al., 2006; Worm et al., 2006; Lester et al., 2009; Sorensen and Thomsen, 2009; Thorpe et al., 2011). Establishment of MPA's may not consider the potential interactions with other spatial closures, physical and biological processes such as ocean currents and phenology, and diverse human uses and responses to the MPA (Katsanevakis et al., 2011).

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[1] http://marineprotectedareas.noaa.gov.

ABSTRACT—In comparison to tropical reef systems, relatively few marine protected areas (MPA's) exist in temperate or subarctic systems (e.g., North Pacific and North Atlantic) where species diversity is lower, abundance of individual species is often higher, and many fish species exhibit large amounts of movement during one or more of their life stages, especially as adults. A review of MPA's in three northern areas—the Northwest Atlantic, Northeast Atlantic, and the Northeast Pacific—indicates that MPA's can be useful management tools towards fisheries management and habitat conservation. However, achieving fishery goals, such as sustainable use of the fisheries resources, will depend on population abundance (relative to unfished conditions) and fish behavior and movement. For example, depleted populations of stationary species such as Atlantic sea scallops, Placopecten magellanicus, *in the Northeast Atlantic and European lobster,* Homarus grammarus, *in the North Sea have responded positively to small MPA's, whereas migratory offshore Atlantic cod,* Gadus morhua, *and Pacific cod,* Gadus microcephalus, *apparently do not appear to benefit from closed areas because of movement into fished areas. Efficient habitat conservation requires detailed habitat mapping on relevant spatial scales. In northern boreal systems with large remote areas, this information is difficult and expensive to access. An alternative strategy of closing and protecting unexploited areas has worked well for the Aleutian Island coral closure area in Alaska. MPA's can be effective fisheries management tools when the species to be protected have been depleted and show a small to moderate level of movement, and reproductive success is ensured. MPA's can be effective at preserving habitat when the design is based on scientific information and takes into account the impact on the user groups.*

For example, an MPA may be created for a single species without consideration of the impact on other species in and out of the MPA (Martell et al., 2005). In other cases, the potential interactions between closed areas for a single fish stock and other fisheries or user groups are ignored if they are outside of the management system. Comparing different MPA types and outcome scenarios in a larger context can help us determine when MPA's are the best solution and when other management strategies might be more effective.

While much of the scientific literature and political discussion has focused on the use of marine protection of tropical ecosystems as related to coral reefs and mangroves, this paper aims to expand the scientific discussion on the use of MPA's as an important element in managing temperate, boreal, and Arctic marine ecosystems (Murawski et al., 2000, Witherell and Woodby, 2005, Fenberg et al., 2012). The number of studies on MPA's has increased over the last 15 years with 5,901 papers published with "Marine Protected Area" in the title, abstract, or keywords since 1991.[2] However, only 306 of these papers (7%) addressed MPA's in northern regions with temperate ocean ecosystems. Area closures as protection measures for habitat preservation, bycatch avoidance, or effort reduction have been used as management tools for decades for a variety of fish and shellfish stocks, marine mammal populations, and seabird colonies in northern temperate regions. However, few such closures were termed "Marine Protected Areas" when they were created, even though under recent definitions by FAO and NOAA they would be identified as such (Witherell and Woodby, 2005).

There are several challenges when designing MPA's in northern ecosystems. First the productivity of these systems is often dominated by a few species of high abundance which tend to occur in areas of high biological production (Rohde, 1992; Gray, 2001), such as Atlantic cod, *Gadus morhua*, in Norway, walleye pollock, *Gadus chalcogrammus*, and yellowfin sole, *Limanda aspera*, in the Bering sea, and haddock, *Melanogrammus aeglefinus*, on Georges Bank (Gray, 1997). The areas of high biological production can vary seasonally and spatially between years, and fish species can undergo large scale seasonal migrations between feeding and spawning grounds (Shimada and Kimura, 1994; Bailey et al., 1997; Comeau et al., 2002; Olsen et al., 2010). It is therefore difficult to establish MPA's for these species that encompass their home range throughout their life cycles, particularly for MPA's that may be in place for specific seasons within a year.

The second challenge is that often the size and remoteness of the areas to be protected hinders data collection. Because the management areas defined for these northern ecosystems are often large with low human population and infrastructure along the coast, we often lack detailed knowledge of the spatial distribution of vulnerable and/or productive bottom habitats such as cold-water coral reefs. This challenge has been addressed in Norway by the seafloor mapping program MAREANO (Marine Areal Database for Norwegian Waters: www.mareano.no) that uses multibeam hydroacoustic technology and underwater camera habitat classification (Buhl-Mortensen et al., 2015). In Canada, the distribution of corals on the western Atlantic coast was identified to prevent damage by the fisheries and petroleum industries (Mortensen et al., 2005; Mortensen et al., 2006). However, such programs are resource- and time-intensive.

Finally, some northern countries, such as the United States and Norway, have sophisticated fisheries management systems that require a lengthy process in order to either implement or adjust MPA's, often involving stakeholder input and complicated legislative and regulatory procedures that can affect the ability to rapidly make management adjustments in these systems. The complicated management structure emphasizes the need to incorporate flexibility into the management process (to the extent possible). Moreover, the issues of spatial and temporal variation in productivity and limited spatial information illustrate the importance of assessing whether MPA's are expected to be the most appropriate management tool.

Our objective in this paper is to review and evaluate the effectiveness of MPA's in Northeast Atlantic (Norwegian), Northeast Pacific (U.S.), and Northwest Atlantic (U.S.) waters (Fig. 1). All three systems have sophisticated fisheries management plans in place that manage fish stocks based on single-species stock assessments, and they allocate total allowable catch (TAC) based on sustainable harvest levels. In addition, in all three systems, area closures have been part of the fisheries management process but were often not designed as part of a comprehensive network of MPA's.

To evaluate the effectiveness, we focus on MPA's with measurable indicators, such as biomass trends from stock assessments or fish or invertebrate densities from scientific surveys. We provide a short overview of each ecosystem, a narrative history as to how the protection measures came into place, and a description of the MPA's goals and objectives. We then examine if those goals have been met and any other effects that occurred as a result of the closures.

Several of the MPA's considered here have been in place for many years, allowing us to analyze their effectiveness in achieving the goals and objectives over the long term. Others, such as the ones in the Lofoten Islands area and for Atlantic cod, are relatively new and will be discussed with respect to design and implementation strategies (Olsen et al., 2007; Buhl-Mortensen, 2017). We arrange our case studies by ecosystem and discuss the MPA's with respect to conservation versus fisheries management goals.

The goal of MPA's for fisheries management is to increase sustainable yields, but this may come with short- and long-term economic costs. Bio-

[2]Author's search in Web of Science, 2016.

mass would increase within the MPA provided that the stock had been fished down below its virgin biomass, and the MPA is larger than the typical scale of fish movement, with stronger responses expected for heavily fished sedentary species. In most circumstances (in particular, if the stock-recruit relationship is always increasing), biomass within the closures cannot increase on average higher than virgin level (assuming unchanged carrying capacity for the stock). Thus, much larger increases inside the closures can theoretically occur for heavily fished stocks than for those that are lightly fished, given similar carrying capacity of the ecosystem as during the time of the virgin biomass.

Secondly, the magnitude of the response also depends on adult mobility. Highly mobile species will leave the closures, and thus it is hard to monitor positive effects on the population. Species of moderate mobility may increase in abundance if at least a portion of the fish remain within the closure, but the population increase will likely be less than that of stationary species because some migration of individuals from the closures to the fished areas will occur.

However, in order to increase yield, there needs to be sufficient "spillover" of larvae and/or adults from the MPA into the fished areas that is greater than the direct loss of yield owing to the MPA (Hart, 2006), and insufficient spillover may not produce a net economic benefit to the fishery (Sanchirico et al., 2006; Gaines et al., 2010). Closing important fishing grounds may lead to a spatial reallocation of effort into a smaller area as well as the loss of yield from fish that remain inside the MPA.

Such shifts in effort can be costly to the fishing industry, because fishing vessels may need to travel further and to areas that may have lower average catch rates or product value (Smith and Wilen, 2003; Haynie and Layton, 2010). Additionally, the redistribution of fishing effort can increase the bycatch of non-target fish species or increase the habitat impact in areas previously not heavily fished. Therefore, it is important to monitor the economic impact of MPA's as well as the biological impact on the ecosystem.

Finally, our goal in examining an MPA system is to identify how it addresses the overarching (and sometimes conflicting) strategic spatial management objectives of conservation and use (Rice and Houston, 2011) and the associated trade-offs and costs. For example, one such tradeoff is between the long-term goals of habitat protection and yield increase and the short-term loss of fisheries.

Ecosystem Descriptions

Norway Northeast Atlantic

The Barents Sea and the Lofoten Islands

The Barents Sea (Fig. 1–3) is a subarctic continental shelf ecosystem (average depth 230 m) bordered in the west by the edge of the continental shelf towards the Norwegian Sea, in the east by Novaya Zemlya, and in the north by the Arctic Ocean (Svalbard archipelago). The convergence of warm Atlantic and cold Arctic waters creates a productive ecosystem that supports high densities of fish, crustaceans, seabirds, and marine mammals (Sundby and Nakken, 2008).

The most important commercially fished species in the Barents Sea are Atlantic cod; haddock; capelin, *Mallotus villosus;* saithe, *Pollachius virens;* and herring, *Clupea harengus*. Herring reside in the Barents Sea only as juveniles while living as adults in the Norwegian Sea and spawning further south along the Norwegian coast. The other four species use the Barents Sea throughout their life history, spawning along the Norwegian coast and drifting into the Barents Sea with the currents during the larval stage (Olsen et al., 2010). The large stocks of pelagic and demersal fish sustain a large fishery from Norway and Russia and a small fleet from the European Union. All fish stocks except saithe are jointly managed between Norway and Russia through the Russian–Norwegian Fisheries Commission.

In the Lofoten Islands area (Fig. 2, 3, 4), the Norwegian continental shelf is at its narrowest and is dominated by shallow banks and deep troughs. Upwelling along the steep continental slope results in high primary and secondary productivity, a large fish biomass, and highly productive fisheries (Sundby and Nakken, 2008). In the transition layer between the cold Norwegian Coastal Current and the warmer, nutrient-rich Atlantic Current lie the spawning grounds of the Atlantic cod. The combination of high plankton production and large eddies off the Lofoten Islands make this area ideal for larval feeding and retention during the first life stages of Atlantic cod (Sundby and Nakken, 2008). In this area, the mapping activity of MAREANO has revealed hundreds of coral reefs and other vulnerable marine ecosystems (VME's) and trawl marks resulting from the high fishing intensity are common (Fig. 3a, 3b).

The North Sea and the Skagerrak Area

The North Sea (Fig. 2, 5) is a shallow sea bounded by the British Isles, continental Europe, and Norway with an average depth of ~100 m (OSPAR, 2000). The North Sea connects to the North Atlantic through the English Channel in the south and the Norwegian Sea in the north. Most of the water masses enter from the northwest, where part of the North Atlantic Drift Current branches off into the North Sea, mixes with different water masses and exits as the Norwegian Coastal Current further north. The North Sea fisheries have been heavily exploited by the surrounding densely populated and industrialized countries. Over the last four decades the offshore oil and gas industry in the region has become very economically important. Environmental concerns include overfishing, runoff from industry and agriculture, oil spills, dredging and dumping, and, in recent years, increasing water temperature.

The continental shelf off the Norwegian Skagerrak coast is narrow and the slope extends down to about 700

Figure 1.—MPA study areas: 1= Barents Sea vulnerable and valuable habitat, 2= Lofoten Island Atlantic cod closures, 3=North Sea sandeel fisheries closures, 4=Skagerrak Lobster reserves, 5= Bering sea crab closures, 6= Aleutian Island coral protection area, 7=- Steller sea lion trawl exclusion zones, 8= Georges Bank fishery closures.

m in the Norwegian Trench (Fig. 2, 6). Except for Denmark, the Skagerrak coastline is complex with numerous smaller fjords and archipelagos, a narrow shelf, and a steep slope. This sets the stage for resident and locally adapted populations of fish (Rogers et al., 2014). Among the commercially exploited species are Atlantic cod; Spanish mackerel, *Scomber scombrus;* European lobster, *Homarus gammarus;* and northern prawn, *Pandalus borealis*. Other species, such as the anadromous brown trout, *Salmo trutta;* and pollack, *Pollachius pollachius*, are often targeted by recreational fishermen. The fish communities along the Skagerrak coast also include several flatfishes (Pleuronectidae), labrids (Labridae), clupeids (Clupeidae), gobies (Gobiidae) and other smaller non-harvested species (Barcelo et al., 2016).

U.S. Northeast Pacific

Eastern Bering Sea

The eastern Bering Sea (Fig. 7) is a diverse subarctic ecosystem that supports some of the world's largest commercial fisheries. The eastern Bering Sea is broadly defined as the area bordered by the Bering Strait to the north, the International Dateline to the west, the Aleutian Archipelago and Alaska Peninsula to the south, and the Alaska mainland to the east. The continental shelf is shallow (less than 200 m) and broad (500–800 km), gradually increasing in depth from the Alaska coast to 180 m at the edge of the continental shelf, with an average depth of 70 m (Hunt and Megrey, 2005) and ending in the abyssal Aleutian Basin in the southwest. It is generally featureless, with the exception of three large and several small islands (NRC, 1996). There are seven large canyons along the slope area of the Bering Sea shelf which are highly productive areas that support spawning and feeding fish and shellfish.

Fisheries in the eastern Bering Sea target many groundfish species that include walleye pollock; yellowfin sole; northern rock sole, *Lepidopsetta polyxystra;* flathead sole, *Hippoglossoides elassodon;* and Pacific cod. Walleye pollock is one of the world's largest commercial fisheries and yellowfin sole is one of the world's largest flatfish fisheries. Pollock replaced yellowfin sole in the mid-1960's as the principal exploited groundfish species. The annual TAC of all groundfish in the eastern Bering Sea and Aleutian Island fisheries is capped at 2 million t.

Major fisheries also target (or targeted) crab species such as red and blue king crab, *Paralithodes camtschaticus* and *P. platypus*, respectively; snow crab, *Chionoecetes opilio*; and Tanner crab, *C. bairdi*. While not as large in terms of landings as the groundfish fisheries, the crab fisheries are very valuable. Each crab stock has undergone dramatic boom and bust cycles over the past several decades, and the various fisheries have been closed at one time or another due to overfishing concerns (NPFMC, 2011a).

Yellowfin sole was the first groundfish species targeted by the eastern Bering Sea commercial fisheries during the late 1960's, while other species were only taken as bycatch (NPFMC, 2011b). Following a decline in abundance of yellowfin sole, other species (principally pollock) were targeted, and total catches peaked at 2.2 million t in 1972. Pollock is now the principal fishery, with catches peaking at approximately 1.3–1.5 million t in years of high recruitment (NPFMC, 2011b).

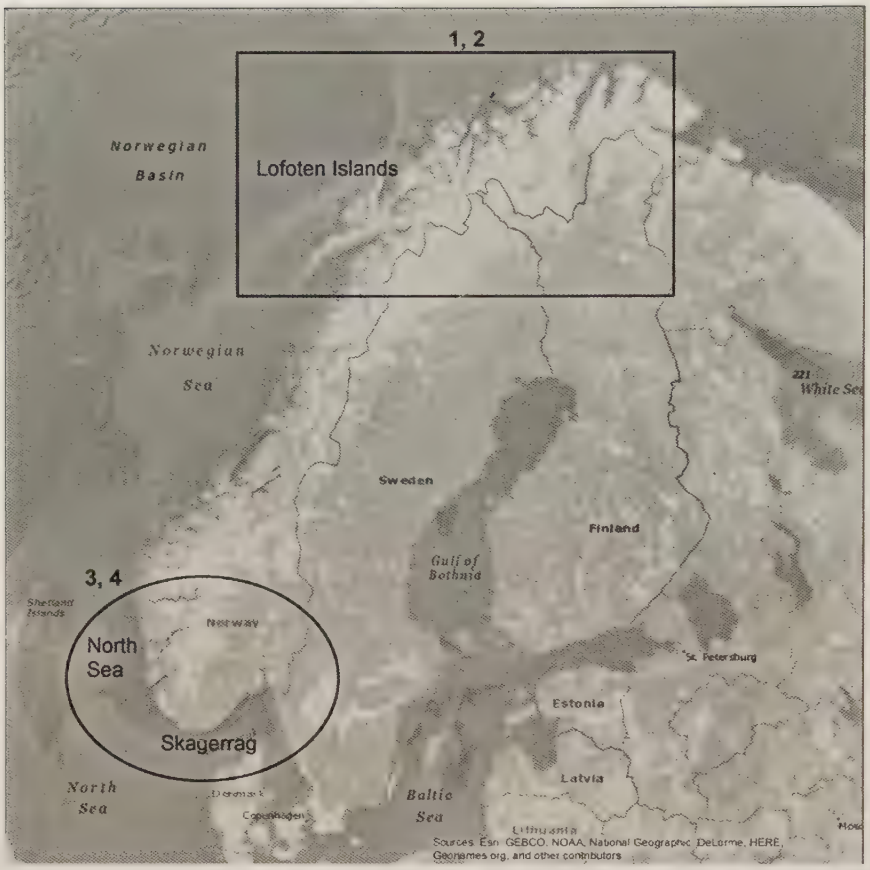

Figure 2.—Study areas in Norwegian waters: 1= Barents Sea vulnerable and valuable habitat, 2= Lofoten Island Atlantic cod closures, 3=North Sea sandeel fisheries closures, 4=Skagerrak Lobster reserves.

After the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) was adopted in 1976, catch restrictions and other management measures were placed on the fishery, and total groundfish catches have since varied from 1 to 2 million t. Total groundfish catches have been below the 2 million t cap. Catches in the eastern Bering Sea and Aleutian Islands for 2016 totaled approximately 1,953,000 t (NPFMC, 2016).

Aleutian Islands

The Aleutian-Commander Islands archipelago extends more than 3,000 km between Alaska and Russia, and forms the southern border of the Bering Sea. The islands are mostly peaks of steep volcanoes surrounded by narrow and steep continental shelves. This region is highly productive and supports large concentrations of seabirds, marine mammals, sessile invertebrates, and fish (Logerwell et al., 2005). The oceanography of the Aleutian Islands is very dynamic (Ladd et al., 2005). The interaction of steep bathymetry with strong tidal currents results in mixing, upwelling, and downwelling in the Aleutian passes and conditions are highly variable on small spatial and temporal scales.

The fishery in the Aleutian Islands started as a foreign fishery mostly targeting Pacific ocean perch, *Sebastes alutus;* and Atka mackerel, *Pleurogrammus monopterygius*, but beginning in 1976 it transitioned to a domestic fleet with the adoption of the MSFCMA and the 200-nmi Exclusive Economic Zone (EEZ). Initially, foreign countries were allocated catch quotas in order to develop the U.S. domestic industry by sharing knowledge about fishing locations and operations, resulting in a joint venture period from 1977 to 1990. Since 1990, the fleet has been entirely domestic (NPFMC, 2016).

Total catches were in excess of 150,000 t throughout the following decade. But in 1999, the pollock fishery was severely restricted due to concerns regarding the fishery's impact on Steller sea lions, *Eumetopias jubatus*. Since then, total groundfish catches have averaged slightly above 100,000 t and are typically about 50% Atka mackerel, 30% Pacific cod, 15% Pacific ocean perch, and 5% other species (Zador, 2014).

U.S. Northwest Atlantic

Georges Bank

Georges Bank is a submerged plateau located east of Massachusetts and southwest of Nova Scotia (Backus, 1987). It measures about 300 km x 150 km (ca. 45,000 km^2); depths are less than 100 m on most of the bank, and are less than 10 m on the shoals in its north-central portion. Because of its high primary productivity and retentive gyre, Georges Bank is one of the most productive fishing grounds in the world (Cohen and Grosslein, 1987).

Commercial fisheries began on Georges Bank in the 18th century, but by the end of the 19th century, overfishing of Atlantic halibut, *Hippoglossus hippoglossus*; Atlantic cod; and large whales was already evident (Hennemuth and Rockwell, 1987; Clapham and Link, 2006). Exploitation of many fisheries reached very high levels in the 1960's and early 1970's, much of it due to foreign factory trawler vessels (Hennemuth and Rockwell, 1987; Fogarty and Murawski, 1998; Overholtz, 2002; Hart and Rago, 2006). When foreign fishing vessels were excluded by the declarations of 200-nmi EEZ by the United States and Canada in 1976, effort in the domestic groundfish and sea scallop fisheries increased, resulting

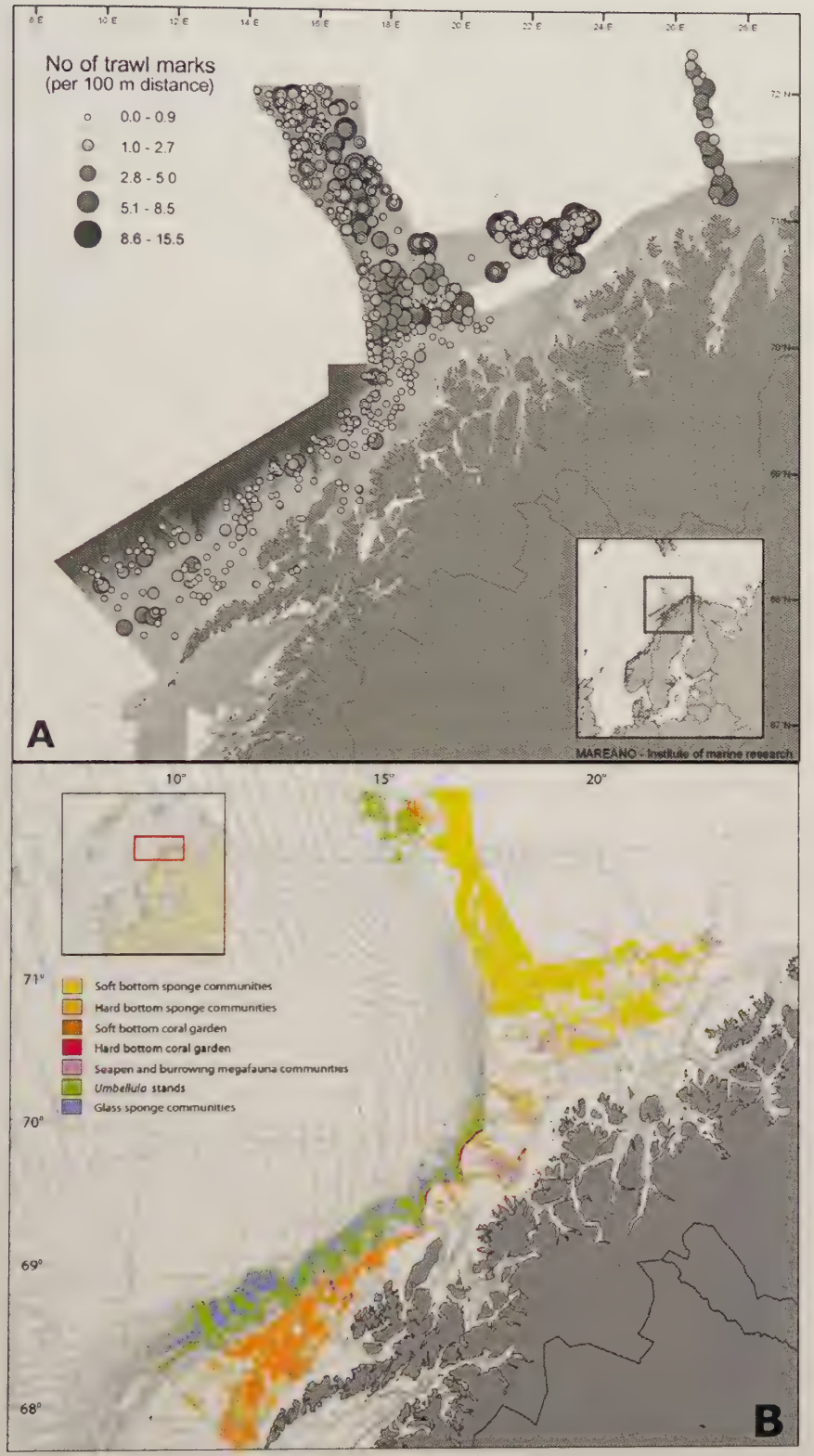

Figure 3.—A) Abundance of trawlmarks (observed no/100 m seafloor) in the Lofoten Vesterålen area (Buhl-Mortensen et al., 2016). B) Distribution of vulnerable habitats in the area mapped by MAREANO (Buhl-Mortensen et al., 2015).

in a collapse in the landings and biomasses of these fisheries in the early 1990's (Fogarty and Murawski, 1998; Hart and Rago, 2006).

MPA Case Study Evaluations

Northeast Atlantic (Norwegian waters)

The establishment of MPA's in Norway has followed multiple paths. However, one common denominator is the 2002 Johannesburg Declaration that initiated the process for sustainable use and ecosystem-based management (EBM) of all living marine resources (United-Nations, 2002). This declaration, together with the Convention on Biological Diversity (CBD), scientific publications (Fernandez et al., 2005; Crowder et al., 2006), and position documents from non-government organizations (NGO's) (Kelleher, 1999; FAO, 2011), has created strong international pressure for implementing marine protection measures.

Establishing ecosystem-based management has led to calls for various forms of integrated management of marine areas, with marine spatial planning (MSP) being the most developed and comprehensive approach (Douvere, 2008). A central part of MSP is the establishment of zoning plans, where MPA's are one of the zoning measures that can be used.

At the start of the century, the Norwegian government initiated a process aimed at managing marine space in its marine ecosystem through regional management plans (Barents Sea, BSMP), Norwegian Sea, and North Sea (Olsen et al., 2007; Ottersen et al., 2011; Olsen et al., 2016) balancing human uses and conservation requirements. In parallel, a process to design a representative network of MPA's in the Norwegian EEZ as part of an integrated management plan was initiated and a preliminary network of MPA's was recommended in 2003. So far only a few of the MPA's proposed in 2003 have been established, but the process is ongoing.

However, Norwegian fisheries management includes the extensive use of

closed areas to protect juvenile fish or reduce bycatch, banning trawling from all areas closer than 4 nmi from the coast, and other measures that are de-facto area-based protection; these management measures are seasonal MPA's. In addition all deepwater *Lophelia* coral reefs have been protected from destructive fishing practices.

Marine Areal Database for Norwegian Waters (MAREANO)

The goal of the MAREANO project is to provide detailed habitat information in support of management plans for Norwegian waters. It was started in 2005 to fill knowledge gaps within the area outside Lofoten that was closed to oil explorations before the revision of the BSMP. This precautionary closure (Fig. 2, 3) was established to prevent oil extraction in a vulnerable and valuable marine area identified in the Barents Sea management plan until more knowledge was available.

In addition, two new management initiatives were implemented in Norway in 2009: the Marine Resources Act[3] and the Nature Diversity Act[4] which both affected spatial allocations to fisheries and oil exploitation. They also highlighted ecosystem management by requiring that all marine organisms caught in the fisheries be reported and that management of marine diversity applies to all levels of the ecosystem from population genetics to habitat diversity.

The MAREANO project mapped an area of 200,000 km^2 from 2006 through 2017. Methods were developed for mapping habitats and biotopes including a procedure for producing maps of predicted biotopes that combined information on the distribution of biological communities with environmental factors and indicators (Buhl-Mortensen et al., 2009; Buhl-Mortensen et al., 2015). Based on the MAREANO mapping, detailed distribution of sensitive and threatened habitats, such as coral gardens and sponge communities, have been provided for the particularly valuable and vulnerable areas identified in the Barents Sea Management Plan (Fig. 3b).

MAREANO also has provided information on such fisheries impacts as trawl marks on the bottom substratum (Fig. 3a) and effects on benthic megafauna, like sponges and corals (Buhl-Mortensen et al., 2015). Trawl impacts were quantified by counting trawl marks along video transects; visible impact was most intense at the Tromsøflaket Bank and in certain regions in the Eggakanten area (Fig. 3a). However, no clear relationship between the satellite tracking data of trawling vessels and the abundance of trawl marks could be established, likely because varying sediment type and current conditions are major factors influencing severity and longevity of trawl marks. This was supported by the observation that in heavily fished areas, more trawl marks are visible on soft bottom than on hard bottom substrate (Buhl-Mortensen et al., 2016; Buhl-Mortensen and Buhl-Mortensen, 2017).

To quantify the effects of bottom trawling, the density of benthic megafauna taxa (e.g., sponges and corals) was studied in video transects from areas of varying fishing intensities (FI) using vessel monitoring system data. Both density and diversity of megafauna were lower in areas with high FI and even low trawling frequency had a negative effect. Vulnerability of the bottom organisms depended on their size, position in the substratum, mobility, and life span/cycle. The effects of bottom trawling on both the substrate and benthic fauna were considered and led to an increased focus on managing the ecosystem effects of fisheries on bottom habitat and benthic fauna (Meld, 2011).

As a result of the mapping by the MAREANO program, the exact position of many reefs is now available and accessible to fishermen using marked seafloor maps, since a law was passed in 1999 making it illegal to trawl on known coral reefs. The new information on locations of coral reefs and effects of bottom trawling on megafauna in the Barents Sea has aided the revision of coral protection areas and is intended to lead to a selection of MPA's that will also protect other vulnerable habitat, such as for sponges and sea pen, from the effects of fishing and oil or gas exploration. These seafloor maps will be useful in achieving the new management objective of the Lofoten–Barents Sea plan, specifically "avoiding damage to vulnerable and valuable marine habitat."

Due to the complex resource management system in Norway involving several institutions and ministries, this process has been time-consuming and cumbersome. Therefore the ultimate management goal of establishing closures and protecting the vulnerable habitat areas has not yet been achieved.

Northeast Atlantic Cod Management Complex (Norwegian Waters)

The Atlantic cod is an important fish species for the fishermen along the Norwegian coast. North of lat. 62°N the Atlantic cod management complex is managed under a merged quota and composed of two separate management units: the larger Northeast Arctic Cod subgroup (NEAC) and the much smaller Norwegian Coastal Cod subgroup (NCC). From the mid-1970's to 2003 the NCC annual quota of 40,000 t was added to the 5–10 times larger quota for NEAC. The total quota has thus been driven mainly by the state of the NEAC stock.

The NCC spawn all along the Norwegian coast at the same time as the NEAC and in some areas, like in Lofoten, overlap the NEAC spawning areas. Since neither fishermen nor buyers can identify the stock of individual fishes by morphology, stock-specific quotas alone will not adequately protect the NCC. The goal of this MPA is to protect the NCC in the Atlantic cod management complex from overfishing during the fishery targeting spawning NEAC. The rebuilding plan for NCC north of lat. 62°N aims to gradually

[3]https://www.regjeringen.no/globalassets/upload/FKD/Vedlegg/Diverse/2010/MarineResourcesAct.pdf

[4]https://www.regjeringen.no/en/dokumenter/nature-diversity-act/id570549/

reduce fishing mortality until research surveys show biomass levels similar to the years 1995–98, when NCC biomass was considered healthy.

The highly migratory NEAC migrate from the feeding area in the Barents Sea to the Norwegian coast to spawn. The main spawning area is the waters east and west of the Lofoten Islands, while a smaller component spawns at various locations along the coast: from Finnmark in the North to Møre in the south, with Borgundfjorden being one of the most important southern spawning grounds. In contrast, the NCC spawn all along the Norwegian coast, and overlap with the NEAC. The fishing intensity on spawning coastal cod has been particularly high in Lofoten and Borgundfjorden areas due to the increased fishing efforts during the spawning runs of the NEAC. Before the mid-1970's, NCC was managed as part of the NEAC stock. However, due to continued decline in NCC survey biomass, the International Council for the Sea (ICES) advised zero catch for the years 2004–11 (ICES, 2009, 2012) and recommended establishing a recovery plan to rebuild the NCC stocks with separate allocations between the two subgroups.

The NCC fishery is regulated much like the NEAC fishery: minimum catch size and mesh size on fishing gears, restriction on bycatch of undersized fish, closure of areas having high densities of juveniles, and seasonal and area restrictions. In recent years additional restrictions on vessel size and fishing gears have been introduced in the fjords and some coastal areas to protect the coastal cod. A rebuilding plan was put in operation in 2011, with closures of spawning grounds during the spawning season as one important regulation tool. To date, seasonal closures have been conducted in two spawning areas: Henningsværstraumen since 2005 and Borgundfjorden since 2009 (Fig. 4). These two areas are known to be important spawning grounds for NCC, but they are also frequented by NEAC during peak spawning.

The criteria for choosing closed areas were based on monitoring the fraction of NCC to NEAC in the surrounding areas. The closure is put into effect by the Norwegian Directorate of Fisheries when the proportion of spawning NCC is 30% of the total spawning cod population. The area in the Lofoten Islands (≈200 km^2) is closed to all fishing activity from 1 Jan. to 30 June, except for fishing with fishing rod and handlines (Fig. 4).

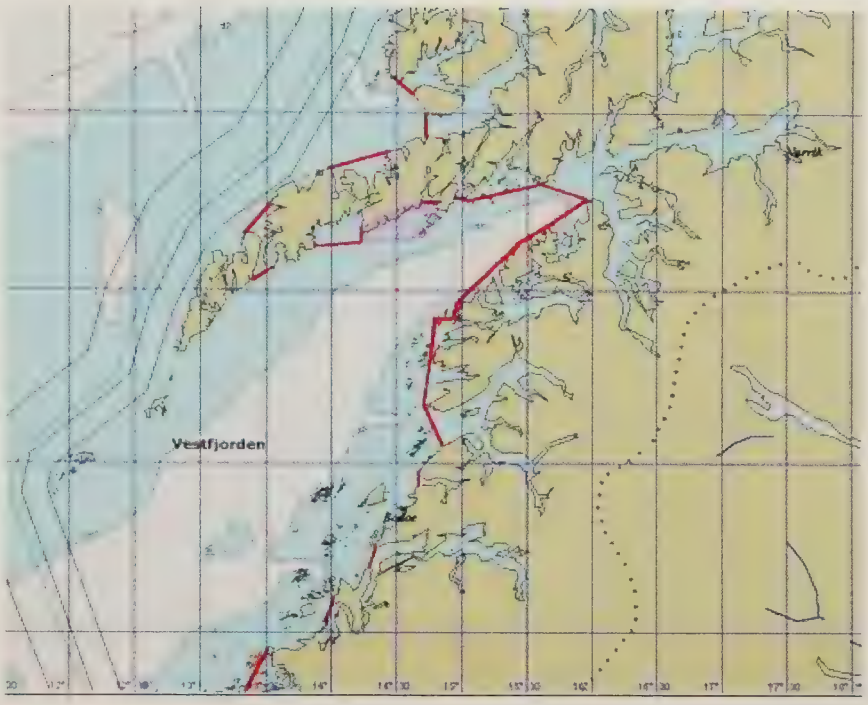

Figure 4.—The shaded area is the closed area in the Lofoten Islands. The red line is the "fjordline" which is the inner border for fishing with vessels larger than 69 feet in the period 1 January to 10 April. The rest of the year these vessels must move outside the "baseline". The area inside the fjordline is only open for vessels smaller than 50 feet, and Danish Seine is not allowed.

In 2012 the regulations were changed to allow small local vessels (smaller than 11 m) to fish in the area. The area is opened for gillnet fisheries with vessels smaller than 15.2 m if the percentage of NCC in the commercial catches outside the closed area is < 30%. This occurred in 2011, and again in 2012, when the percentage of NCC in the catches was < 10%. The area in Borgundfjorden (Fig. 4) is closed to all fishing from 1 March to 30 April, except for fishing with handlines and fishing rods. The criteria for opening this area are the same as in the Lofoten Islands, but the limit has never been reached.

North Sea Lesser Sandeel

The goal of the MPA's for lesser sandeel, *Ammodytes marinus*, was to mitigate the effects of local overfishing on the sandeel stocks by using area-based management tools. Rotational fishing closures are the type of MPA's used for sandeel in Norway. Lesser sandeel is a small species that buries itself in the sand during most of its life. Because of the species' dependency on suitable habitat, sandeel fishing grounds are distributed in the North Sea in a spatial patchwork (Fig. 5). The high abundance of sandeel in the North Sea has made it a target for a commercial fishery since the 1950's.

Sandeel are trawled during the daytime when the fish are feeding in dense schools. Sandeel have supported the largest fishery in the North Sea with average annual landings of ~800,000

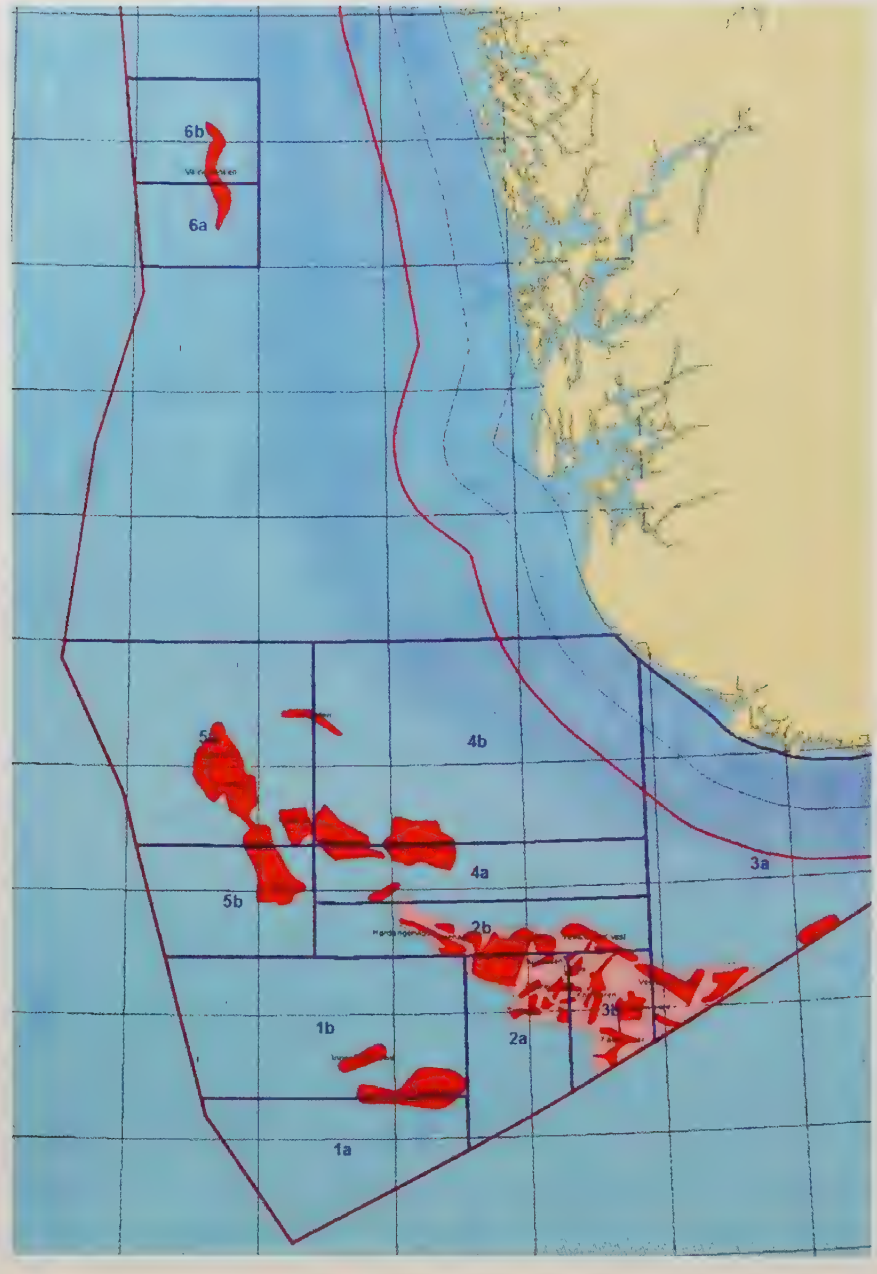

Figure 5.—Sandeel fishing grounds in the Norwegian EEZ. Red indicates trawling areas, pink scattered sandeel populations in areas that are too small for trawling (natural refuges), and blue lines depict the new spatial management plan.

t during the past three decades. However, in 2003 landings dropped suddenly to ~300,000 t. The decrease was particularly severe in the Norwegian EEZ (90–95% in some years), where several fishing grounds have not provided landings during the last decade (ICES, 2009).

Because the species is an important trophic link in the North Sea ecosystem and serves as prey for a variety of predators (e.g., birds, fish, and marine mammals), the poor condition of the sandeel stock may have a negative impact on the entire North Sea ecosystem. This is further exacerbated by substantial spatial contraction of the stock along with the substantial decline of available biomass. Individual sandeel fishing grounds are split into two subareas. One subarea is fished in one year and the second the following year. If the abundance on a fishing ground falls below a predefined level, the entire fishing ground is closed.

The total allowable catch (TAC) for all open areas was estimated using biomass estimates from acoustic surveys. Sandeel become mature at the age of two. Hence, alternating closures of two subareas of each fishing ground is intended to maintain local spawning stocks, prevent local depletions, ensure sufficient prey for predators, and maximize fishing yield. This spatial management regime was introduced in 2010. To date, the results have been promising. All fishing grounds that were initially opened in 2010 were still open for fishing in 2012, even though recruitment was poor in 2010 and 2011 (ICES, 2012), a situation that would normally have resulted in overfishing and local depletions. Since the area closures have been put into effect, the estimated biomasses have been above the threshold level that would have closed fishing in three of the fishing grounds.

Although the results of the new spatial management regime have been promising, there are still questions that remain unanswered before concluding that these MPA's are effective in the long term. First, sandeel prefer relatively coarse sand, and when fish are removed from their optimal habitat by fishing, the fished area is likely to be replenished by sandeels from more marginal habitats (Holland et al., 2005; Wright, 1996). Thus, if the preferred sandeel habitat lies in the area open to fishing and the quality of the habitat is substantially lower in the closed area, then migration from the closed subarea into the area open to fishing could occur within one fishing season, and the local stock could still be vulnerable to overfishing.

If, on the other hand, migration into the closed area from the open area

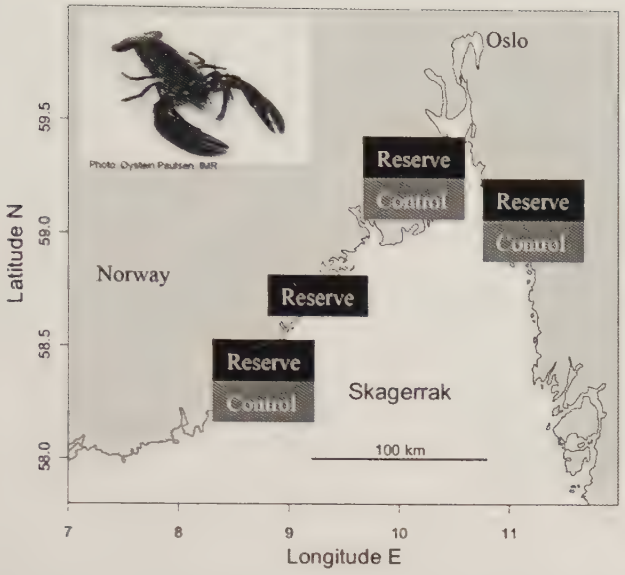

Figure 6.—Lobster reserves and control areas (for evaluating reserve effects on population density and demography) on the Norwegian Skagerrak coast. For detailed maps, see Pettersen et al. (2009).

should occur between two fishing seasons, then this could reduce fishing yield. These problems can be addressed by redesigning the subareas, based on the acoustic survey. Second, the underlying mechanism of recruitment remains unresolved, although empirical evidence suggests that local spawning stocks are important for local recruitment. Therefore it is possible that there are other causes for local recruitment failures, such as changes in local retention for sandeel larvae or changes in the local availability of planktonic prey.

MPA's for Lobster and Cod in Coastal Skagerrak, Southern Norway

A network of MPA's has been implemented specifically targeting the European lobster, *Homarus gammarus,* along the coast of southern Norway. The main objective is to provide a scientifically based evaluation of MPA's as a management tool for restoring this intensively harvested population (Kleiven et al., 2011; Moland et al., 2011). The European lobster is a prized catch for both recreational and commercial fishermen in the Skagerrak, the northeastern area of the North Sea. However, since the 1950's the lobster population in this region has been in severe decline (Pettersen et al., 2009). In response to this population decline, four lobster MPA's were established in September 2006 (Fig. 6). The MPA's are small (0.5–1 km^2) and were intended to be experimental in nature, excluding the use of standing gear such as traps, longlines, and gillnets. Hook and line fishing for species such as the Atlantic cod is still permitted inside the MPA's.

The lobster MPA's were designed in collaboration with local commercial fishermen. Recreational fishermen, on the other hand, were not included in the implementation process although many of them expressed that desire (Pettersen et al., 2009). Recreational fishermen are an important stakeholder group and contribute the majority of fishing effort for lobster in Skagerrak (Kleiven et al., 2011). Therefore, one lesson learned was that recreational fishermen should be included in future MPA implementation and assessment processes.

The lobster MPA's have been monitored annually since 2004 (3 years before implementation). Since 2006 (before implementation), adjacent control areas, where lobster fishing was permitted, were added to the study. The survey design therefore follows the BACIP (Before-After-Control-Impact-Pairs) design as advocated in other studies (Russ, 2002) as a general guide to measuring reserve effects. By 2010 (4 years after MPA designation), lobster population density had almost tripled inside the MPA's and there was also a significant increase in mean body size (Moland et al., 2013). A similar increase in population density and body size was not observed in the control areas. These results indicated that MPA's can be a useful management tool in rebuilding lobster populations in northern temperate waters. Note, however, that spillover and recruitment benefits to adjacent fished areas have not yet been observed.

In one reserve and control area, the local population of Atlantic cod has also been monitored. By 2010 both the survival and population density of larger cod had increased inside the MPA compared to adjacent control areas (Moland et al., 2013; Fernández-Chacón et al., 2015). Coastal cod in this region is known to be highly stationary, with fjord-specific local populations that are also depleted and intensively harvested by commercial and recreational fishermen (Knutsen et al., 2003; Olsen and Moland, 2011; Kleiven et al., 2016). Therefore, it is perhaps not surprising that Atlantic cod also benefit from the MPA's due to the exclusion of fixed fishing gear. Informed by these encouraging results, another MPA was implemented in 2012 to protect a local Skagerrak fjord population of Atlantic cod. This MPA covers about 1.5 km^2 of the fjord around a key cod spawning area and excludes all forms of fishing and thus is Norway's only true no-take marine reserve. It offers protection to the coastal cod population, although long-term effects on recruitment and population density of larger fish still needs to be evaluated (Villegas-Ríos et al., 2017).

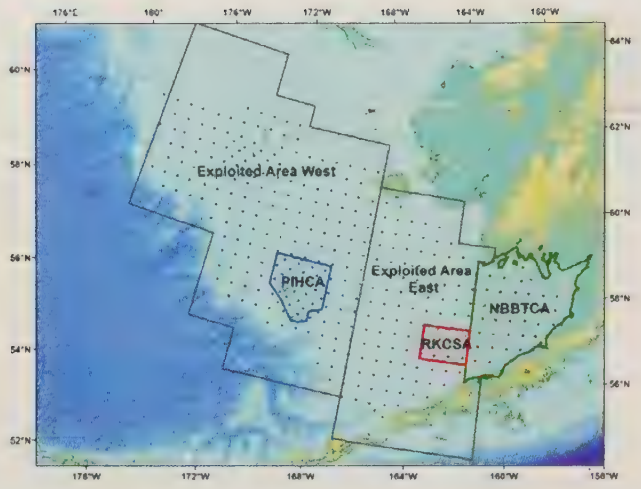

Figure 7.—Three principal large-scale marine protected areas in the eastern Bering Sea: the Pribilof Islands Habitat Conservation Area (PIHCA, in blue), the Red King Crab Savings Area (RKCSA, in red), and the Nearshore Bristol Bay Trawl Closure Area (NBBTCA, in green). Also shown are the nominal locations of bottom trawl sampling stations (dots) in the annual eastern Bering Sea bottom trawl survey conducted by the Alaska Fisheries Science Center and the two "exploited" areas used to classify individual survey hauls ("Exploited Area West," "Exploited Area East"; grey outlines).

Northeast Pacific (U.S. Waters)

Area closures have been used as fishery management tools off Alaska long before they became known as Marine Protected Areas. Currently, there are several regulatorily established Habitat Conservation Areas, such as seamounts, coral protection areas, and no-trawl zones. In one example, we focus on the first such "MPA" in Alaska waters; it was established in 1939 when Cook Inlet and all waters east of long. 150°W were closed to trawling for red king crab, *Paralithodes camtschaticus*, in an effort to reduce exploitation of red king crab and Pacific halibut, *Hippoglossus stenolepis* (Witherell and Woodby, 2005). At present, more than 40 MPA's have been established by fishery managers in federal waters off Alaska (i.e., beyond the 3 nmi state waters boundary) to address a diverse range of purposes including protecting ecological structure and function, improving scientific understanding, conserving habitat, protecting vulnerable stocks, and preserving cultural resources (Witherell and Woodby, 2005).

Red King Crab and Blue King Crab Savings Area

Three large-scale MPA's in the eastern Bering Sea are evaluated here (Fig. 7). The three large closed areas are not "marine reserves" (*sensu* Lubchenko et al., 2003) where no extractive activities are allowed. Rather, the primary goal of all three closures is sustainable production and exploitation of local crab stocks (red king crab in the Nearshore Bristol Bay Trawl Closure Area (NBBTCA), and the Red King Crab Savings Area (RKCSA), and blue king crab in the Pribilof Islands Habitat Conservation Area (PIHCA)) by prohibiting bottom trawling and therefore eliminating crab bycatch and benthic habitat disturbance from groundfish trawl fisheries. Targeted fishing for crab using pot gear is allowed, as is fishing for groundfish using longline, pot, and, in some instances, pelagic trawl gear.

The NBBTCA (65,000 km^2) was established in 1997 as a year-round closure to all trawling (bottom and pelagic) in all of Bristol Bay east of long. 162°W, except for a small area that is seasonally open to trawling in the spring (from 1 Apr. to 15 June). This expanded previous smaller protected areas in Bristol Bay in place from 1975 until 1983, to protect the Bristol Bay red king crab stock from effects of groundfish trawl fisheries and to reduce gear interactions between the crab pot and groundfish trawl gears.

In 1983 the area was opened to developing domestic trawl fisheries, even though the crab stock had collapsed in 1981. In 1986, a 27,000 km^2 area in the middle of Bristol Bay was closed to bottom trawling and in 1997 this was expanded to become the NBBTCA. The adjacent RKCSA (14,000 km^2) was also permanently closed to bottom trawling north of lat. 56°10'N. South of lat. 56°10'N to 55°N, the RKCSA is open to limited bottom trawling, but only in years when a directed fishery for Bristol Bay red king crab is also allowed. Northern rock sole are the primary target of bottom trawling in the limited area. Finally, the PIHCA (24,000 km^2) prohibited all trawling and dredging beginning in 1995 to protect the local stock of blue king crab.

Data from the long-term fishery-independent trawl survey in the eastern Bering Sea (Lauth, 2011) conducted by the Alaska Fisheries Science Center (AFSC) was used to perform a Before-After-Control-Impact (BACI) analysis (Stewart-Oaten et al., 1986) of the effects of the three large MPA's on the abundance of several ecologically and commercially important groundfish and crab stocks. Each survey station was classified into one of five analysis regions (Fig. 7): two areas (control sites) that have been continuously open to exploitation ("Exploited Area West," "Exploited Area East") and the three closed areas (impact sites).

We calculated mean CPUE for each analysis area by survey year as an index of relative abundance by species within each area (Fig. 8). Mean CPUE from the AFSC summer bottom trawl survey is routinely used to track changes in fish and crab abundance in the stock assessments for most federally managed stocks. The period 1990–94 was

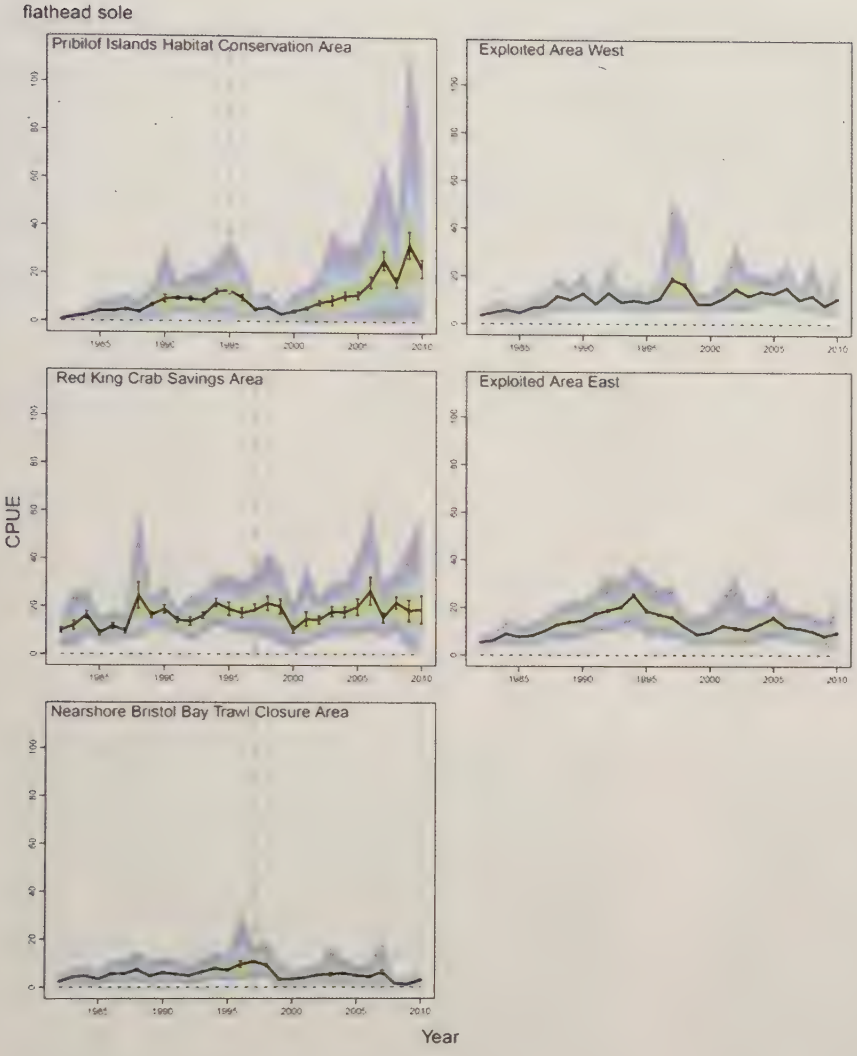

Figure 8.—Example time series for flathead sole from each analysis area of mean catch per unit of effort (black line), based on 10,000 bootstrap samples, with bootstrapped standard error (error bars) and confidence intervals (colored intervals). The dashed grey vertical line indicates the year in which each closed area was established. The grey hatched areas indicate the "before" (1990–94) and "after" time periods used in the before-after-control-impact (BACI) analysis.

defined as the "before" time period and 2006-10 as the "after" time period in the BACI analysis. We then tested whether the average ratio of abundance inside to outside each closed area changed in a positive manner from before to after the MPA was implemented. We included 5 flatfish species, 4 other groundfish species, 2 crab species, and 5 habitat-forming invertebrate species/taxa in the analysis (Table 1).

We were able to make 35 valid comparisons (out of a possible 48) (Table 1). We found a range of effect sizes, both positive and negative, for relative changes in CPUE within the three closed areas examined, relative to the adjacent exploited area and across the species/taxa. Three significant positive effects, ($p \leq 0.01$) occurred for sea peaches, *Halocynthia* sp., and sea raspberries, *Eunephthya,* in the NBBTCA and for rock sole, *Lepidopsetta* spp., in the PIHCA.

Altogether, we found significant positive changes in relative CPUE ($p \leq 0.05$, not accounting for multiple comparisons) associated with at least one of the closed areas for all five flatfish species, three of the four "other" groundfish species, two of the five habitat-forming benthic invertebrate taxa, but neither of the crab species (Table 1). Only rock sole, flathead sole, and Pacific cod exhibited positive effects in more than one closed area.

Conversely, we found significant negative changes in relative CPUE ($p \leq 0.05$) associated with at least one of the closed areas for two of the five flatfish species, two of the four "other" groundfish species, one of the two crab species, and two of the five habitat-forming invertebrate taxa. However, only Tanner crab and sea peaches exhibited significant negative effects in more than one closed area. The largest significant negative effects ($p \leq 0.05$) occurred for sea peaches in the RKCSA and sea onions, *Boltenia* sp., and Tanner crab in the NBBTCA.

The three MPA's we examined were closed to bottom trawling to reduce bycatch of several crab species in fisheries for groundfish. These closed areas were open to other gear types and were not intended to restrict the crab fisheries. Based on fishery observer data, compliance with these closed areas by the groundfish bottom trawl fishery appears to be good, and substantial effort by the groundfish trawl fisheries in these areas prior to closure has been eliminated or displaced (Fig. 9). We found no significant increases in relative abundance in any of the three closed areas for the two crab species (snow and Tanner) we examined.

Quite the opposite, we found that relative abundance decreased significantly for Tanner crab in both the NBBTCA and RKCSA areas. However, this may reflect relatively higher fishing mortality on crab stocks within the areas closed to bottom trawling because targeted crab fisheries are conducted within these areas. Of the 14 other taxa (9 groundfish species and 5 habitat-forming benthic invertebrate taxa) which we were able to examine, only rock sole exhibited significant

Table 1.—Results of abundance comparisons between closed and exploited areas for selected species and taxonomic groups, based on mean CPUE from the annual eastern Bering Sea Groundfish and crab survey. Significance levels for a closed area effect are based on empirical bootstrapped probability distributions of the effect size (see text for more detail). Highlighting corresponds to empirical significance level for a positive closed area effect (dark green: <0.001, medium green: 0.001–0.01, light green: 0.01–0.05, none: 0.05–0.95, light red: 0.95–0.99, medium red: 0.99–0.999, dark red: > 0.999). Significance levels for a negative closed area effect are 1-p, where p is the significance level for a positive effect.

	Closed area:	Nearshore Bristol Bay Trawl Closure Area		Red King Crab Savings Area		Pribilof Islands HCA	
	Exploited area:	Exploited Area East		Exploited Area East		Exploited Area West	
Common Name	Taxonomic name	Effect size	Significance	Effect size	Significance	Effect size	Significance
Flatfish							
Alaska plaice	*Pleuronectes quadrituberculatus*	0.5725	0.0068	0.1787	0.2347	–0.5613	0.9954
Arrowtooth flounder	*Atheresthes stomias*	—	—	0.7330	0.0089	0.1130	0.3143
Flathead sole	*Hippoglossoides elasodon*	0.0233	0.4799	0.8199	<0.001	0.7706	0.0037
Rock sole	*Lepidopsetta* spp.	0.2857	0.0203	0.4389	0.0197	0.9775	<0.001
Yellowfin sole	*Limando aspera*	0.4183	0.0021	–0.1703	0.8437	–0.5510	0.9866
Other groundfish							
Great sculpin	*Myaxocephalus polyacanthocephalus*	0.3759	0.0987	–0.4956	0.9157	0.9757	0.0020
Pacific cod	*Gadus macrocephalus*	–0.6345	0.9944	0.7888	0.0035	0.4795	0.0207
Plain sculpin	*Myaxocephalus jaok*	0.3891	0.0282	—	—	—	—
Walleye pollock	*Theragra chalcogramma*	–0.7382	0.9876	0.0999	0.4076	0.2579	0.0952
Crab							
Snow crab	*Chionoecetes opilio*	—	—	—	—	0.0575	0.5871
Tanner crab	*Chionoecetes bairdi*	–1.4389	<0.001	–0.6776	0.9951	—	—
Habitat-forming invertebrates							
Mussels	Mytiladae	–0.4013	0.7006	—	—	—	—
Sea onions	Boltenia	–1.5017	<0.001	—	—	—	—
Sea peaches	Halocynthia	7.3070	0.0029	–2.4275	0.9998	–0.8570	0.9505
Sea potato	*Styela rustico*	—	—	—	—	0.6171	0.1531
Sea raspberries	Eunephthya	1.6204	<0.001	—	—	–0.5675	0.7170

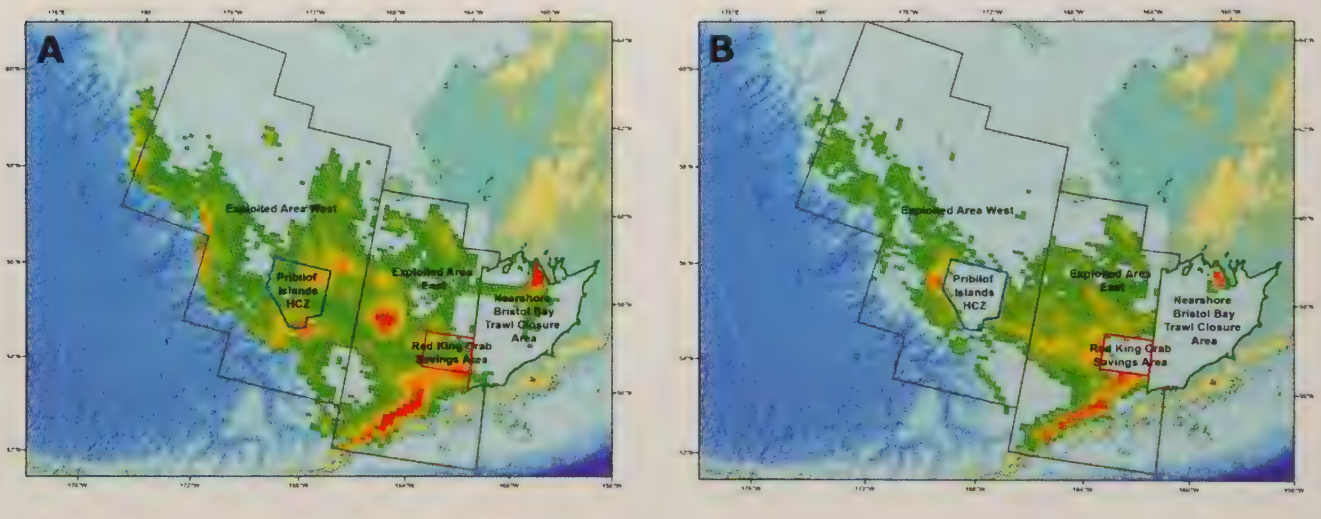

Figure 9.—Distribution of bottom trawls in the eastern Bering Sea groundfish fisheries, as recorded by fishery observers, for 1990–94 (prior to area closures; left) and 2006–10 (after area closures; right), binned in 0.5° longitude *x* 0.2° latitude cells. Cells with fewer than 3 hauls/time period are not shown due to confidentiality restrictions. The same color scale is used in both maps; colors run from green (few hauls) to red (many hauls).

positive increases in relative abundance across all three closed areas.

As a group, the flatfish species appear to have benefited most consistently from the closures, with significant positive effects on relative abundance in over half (8 of 14) of the cases examined. This may be because flatfish are relatively stationary species compared to other species targeted by the bottom trawl fishery, such as Pacific cod. Pacific cod is also harvested in the eastern Bering Sea in large quantities, but it moves across the boundaries of the closures and therefore observation of a biomass increase inside the closed area is less likely for this species.

Altogether, we found 14 instances out of 35 taxon/closed-area combinations tested that exhibited "significant" increases in the relative abundance of the taxon in the closed area in the time following the closure. Conversely, we found 9 instances in which the relative abundance of the taxon in the closed area declined significantly. To

some extent, these results suggest that the response to areas closed to bottom trawling is inconsistent across species and areas for many species. The closed areas have certainly had relatively little positive effect on the targeted crab stocks. Closing these areas to bottom trawling alone, but not to crab harvest by pots, does not appear to be enough to recover depleted crab stocks.

Aleutian Islands
Coral Protection Area

The Aleutian Islands coral protection areas (Fig. 10) were established to protect vulnerable habitat from the impacts of bottom trawling. Future bottom trawling was limited to where there had been medium or high historical bottom trawl effort between 1990 and 2001. All areas which had low or zero effort at fishable depth (over 58,000 km^2) were closed to all future bottom trawling in 2007 as a precautionary measure (NMFS, 2001). In addition, bottom trawling in areas that had a high rate of bycatch of corals and sponges and low catch rates was prohibited.

This closure created an MPA in the Aleutian Islands that closed over 75% of fishable depths (up to 1,000 m) to all bottom trawling, leaving an area of 26,555 km^2 open to trawling in the Aleutian Islands, containing 94% of past effort and 97% of catch. This closure was only possible because of the existing data from a large fishery observer program and close cooperation of the industry. Additional bycatch limits for coral and sponges were imposed as an additional protection measure; these were set near the upper end of the observed bycatch levels for these taxa.

There was one adjustment to the boundaries of this large MPA since its implementation in 2007, which consisted of an exchange of areas in the far western Aleutian Islands. Additionally, conservation measures to protect Steller sea lion prey implemented in 2011 (see below) closed much of the western and central Aleutian Islands to harvest of Atka mackerel and Pacific cod, the top two fisheries in the Aleutian Islands, which will complicate the analysis of the efficacy of the coral closures.

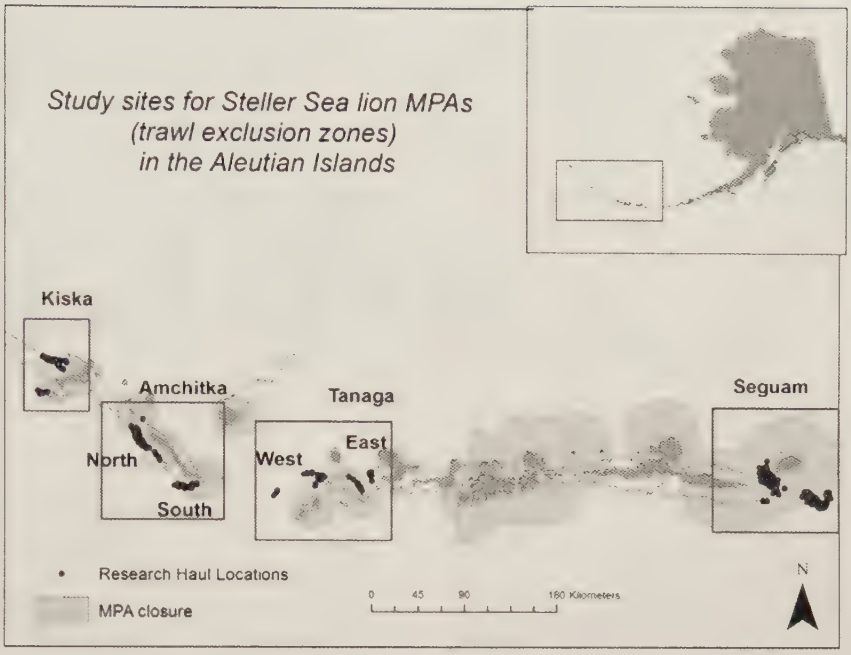

Figure 10.—Study sites and haul locations inside and outside Steller sea lion MPA's

Steller Sea Lion
Trawl Exclusion Zones

The other MPA's established in the Aleutians Islands are fishing closures around Steller sea lion (SSL) rookeries (Fig. 10). The goal of these MPA's is to protect major SSL prey species from the effects of fishing within sea lion critical habitat.

The Alaska SSL population has declined by more than 80% since the 1970's (Loughlin, 1998). In 1997, the western population (west of long. 144°W) was listed as endangered under the Endangered Species Act (ESA). In November 2000, a suite of protection measures was implemented to mitigate potential competition between fisheries and sea lions. Since then, 10 and 20 nmi diameter MPA's (known as Trawl Exclusion Zones (TEZ's)) have been in place around major SSL rookeries and haulouts to protect SSL critical habitat (Fig.10)

In response to these MPA closures, NMFS conducted local-scale studies in 2002–04 and 2006–07 to examine the abundance and movement of Atka mackerel within and adjacent to the MPA's. Atka mackerel are a major prey species of the western stock of SSL (Sinclair and Zeppelin, 2002).

The potential effect of MPA closures examined for the purpose of this paper are that MPA's result in the increase of fish biomass inside the closed area. This study was originally designed as a tag release and recovery program for Atka mackerel (McDermott et al., 2005). During the tag recovery on chartered survey vessels, the area swept, catch, and species composition were recorded. We compared CPUE inside vs. outside the closed areas to examine the hypothesis of increased relative abundance of Atka mackerel inside the MPA's.

To test for differences in average CPUE inside vs. outside the MPA, we analyzed each area separately and used an ANOVA (Titco Spotfire SPLUS) with year as a factor. In the Tanaga and Amchitka areas, we further divided the study areas into subareas, Amchitka North and South and Tanaga East and West (Fig. 10). Each subarea

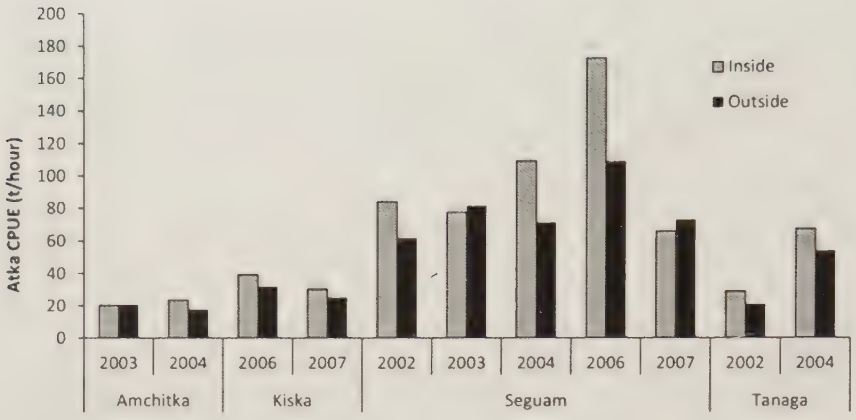

Figure 11.—Atka mackerel catch per unit of effort inside (gray) and outside (black) the trawl exclusion zones in the different study areas and years

represented a separate population center within the study area. For Tanaga and Amchitka the ANOVA included year and subarea as factors when testing for differences of CPUE inside and outside the MPA. To test for differences in mean length within study areas, we used an ANOVA (Titco Spotfire SPLUS) with year, season, and sex as factors.

Atka mackerel CPUE was significantly different inside vs. outside the MPA at Seguam Pass (P=0.003) but was not significantly different at Amchitka (P=0.84), Tanaga (P=0.74), or Kiska (P=0.36) (Fig. 11). The results of Atka mackerel CPUE differences might be explained by oceanographic and habitat differences of study areas and by the MPA size (i.e., 10 vs. 20 nmi). At Seguam Pass, for example, the MPA boundary is 20 nmi and happens to contain a well-documented frontal region characterized by upwelling and stratified water (Coyle, 2005; Mordy et al., 2005) This area may favor feeding (Rand and Lowe, 2011) and reproduction (Cooper and McDermott, 2011). The population of Atka mackerel inside the MPA is separated from the outside population by an area of low Atka mackerel abundance which forms a natural boundary. At the Tanaga, Amchitka, and Kiska study areas, the MPA boundary is 10 nmi and in some cases, such as Amchitka, the MPA boundary bisects preferred Atka mackerel habitat and fish movement across this boundary is presumably high as tagging data have shown (McDermott et al., 2015).

In summary, it appears that in areas where fish could move freely across the MPA boundary, there was no difference in relative abundance inside vs. outside the MPA's. However in the areas where the MPA was larger and fish aggregations were separated by a natural boundary, the relative abundance of Atka mackerel was higher inside the closed area.

Groundfish and Sea Scallop Stocks in the Georges Bank Ecosystem

MPA's (Fig. 12) were established in December 1994 to help rebuild important and severely depleted groundfish and sea scallop, *Placopecten magellanicus*, stocks in the Georges Bank ecosystem. In general, the MPA's were closed to bottom trawling and dredging for groundfish and sea scallops, with some limited fishing in portions of the MPA's for sea scallops, yellowtail flounder, *Limanda ferruginea*, and haddock, *Melongrammus aeglefinus*, during some periods since 1999.

Prior to 1994, these three areas were closed during late winter and spring to protect groundfish spawning aggregations. Thus, the MPA's were not originally designed as year-round closures. Besides the closures, a number of other management measures were enacted starting in 1994. Specifically, the sea scallop and groundfish fisheries changed from open access to limited access management in 1994, with a fixed number of permits. Each permit holder was given annual days-at-sea and/or quota allocations. Gear regulations were also gradually imposed

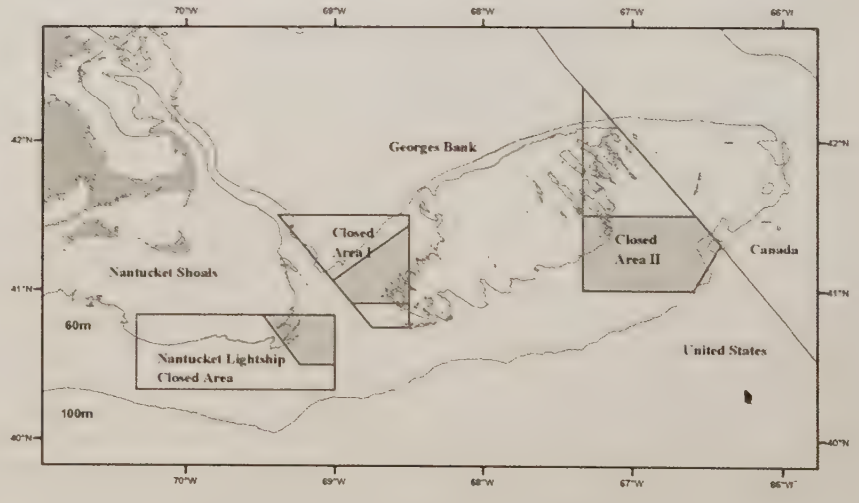

Figure 12.—Chart of Georges Bank and Nantucket shoals, showing the three closed areas. The shaded portions are sea scallop access areas, where limited amounts of scallop fishing have been permitted since 1999.

that increased dredge ring size for the scallop fishery and mesh sizes in the groundfish fishery potentially contributing to some of the stock rebuilding since 1994.

The responses to these closures of five important commercial species on Georges Bank and Nantucket Shoals are examined here: sea scallops; yellowtail flounder; goosefish, *Lophius americanus* (also known as monkfish or American anglerfish); haddock; and Atlantic cod. Sea scallops and goosefish are managed as separate fisheries, whereas yellowtail flounder, haddock, and cod are managed as part of the Northeast U.S. multispecies groundfish complex. The goosefish fishery was not managed prior to 1999, but since then this fishery has been managed with days-at-sea, quotas, and gear regulations similar to the sea scallop and multispecies groundfish plans (Haring and Maguire, 2008).

Two separate stocks of yellowtail flounder are examined: Georges Bank yellowtail flounder, whose stock area includes most of Closed Areas I and II and the portions of Georges Bank outside these areas, and southern New England yellowtail flounder, whose stock area includes the Nantucket Lightship Closed Area and all other areas south and west of Georges Bank (Fig. 12). The response variables used in the analyses were estimates of overall biomass, recruitment, and fishing mortality from stock assessments. In addition, biomass trajectories in the closed and open areas were examined (Hart and Rago, 2006).

Estimated biomasses from stock assessments (Fig. 13) suggest strong responses to the closures in two stocks: Georges Bank sea scallops and Georges Bank haddock. In both cases, biomass began increasing almost immediately after the closures in 1994, and the terminal year biomass was over an order of magnitude higher than in 1994. Sea scallops inside the closed areas showed a strong response to the closures, especially in the first 6 years after closure (Fig. 14). Scallop abundance outside the closed areas has also increased, though the increase was more gradual and less than that observed in the closed areas, likely due to the effort reductions and gear restrictions.

Georges Bank yellowtail flounder appears to have had a more modest response to the closures (Fig. 13). A sharp reduction of this stock's biomass occurred between 2004 and 2005, when a "Special Access Program (SAP)" allowed substantial landings of yellowtail flounder in the southern portion of Closed Area II. The stock then began to recover due to a strong year class but appears to have declined since 2008. The biomass inside the MPA's increased substantially within the closures from 1996 to 2003, but then dropped precipitously coinciding with the SAP fishery in Closed Area II in 2004 (Fig. 14). After a recovery, mainly due to a large year class, biomass within the closures declined considerably between 2009 and 2011, even though there was no directed fishery for yellowtail flounder in the closed areas. Biomass in the open portions of Georges Bank has been low.

Biomass of southern New England yellowtail flounder remained at low levels since 1994 (Fig. 13), and has shown marginal increases within the Nantucket Lightship Closed Area (Fig. 14). Estimates of biomass in the open areas of southern New England are unavailable because the scallop survey does not cover the entire area sufficiently.

Goosefish showed little response to the closures after 1994. The modest increases that occurred after 1999 were likely due to strong recruitment and implementation of the fishery management plan in 1999 rather than to the closures. Goosefish biomass tended to be slightly less inside the closures than outside prior to the closures in 1994, but this relationship appeared to be reversed after the closure, suggesting that the closures had a small protection effect. Biomass of the remaining two stocks, southern New England yellowtail flounder and Georges Bank cod, showed no response to the closures.

Recruitment of Georges Bank haddock and yellowtail flounder was higher after the closures than in the period immediately prior to the closures, but even in these cases, recruitment after the closures was not higher than it was early in the time series (prior to 1964 for Georges Bank haddock and 1982 for Georges Bank yellowtail). Recruitment in Georges Bank cod and southern New England yellowtail flounder has been very poor since the closures, and the closures do not appear to have substantially affected recruitment of goosefish. Recruitment of Georges Bank sea scallops was slightly higher after the closures than before (Hart et al., 2013).

The characteristics of the six stocks examined are summarized in Table 2. Five of the stocks were severely depleted at the time of the closures due to very high fishing mortalities. The one exception was goosefish, which did not have a directed fishery until the mid-1980's, and whose fishing mortality appears to have been fairly low prior to the closures (NEFSC, 2010). Sea scallops can swim short distances, but their movement is negligible on the scale of the closures. Yellowtail flounder, goosefish, and haddock are all capable of greater movement than scallops, but none typically undergo large-scale migrations, and so their mobility is classified as moderate. Cod can move several hundred kilometers during seasonal migrations; therefore they are classified as highly mobile. Haddock, cod, and both yellowtail stocks all showed evidence that recruitment had decreased as the stock biomass declined, suggesting recruitment overfishing, whereas there was little or no evidence for recruitment overfishing of scallops and goosefish.

Discussion

Achieving MPA Goals

The MPA's discussed in this paper can be divided into two broad groups based on the stated goals: 1) to conserve habitat or fish species to preserve the functioning of a healthy ecosystem (Habitat Conservation MPA's), and 2) to prevent overfishing or stock depletion (Fishery Management MPA's).

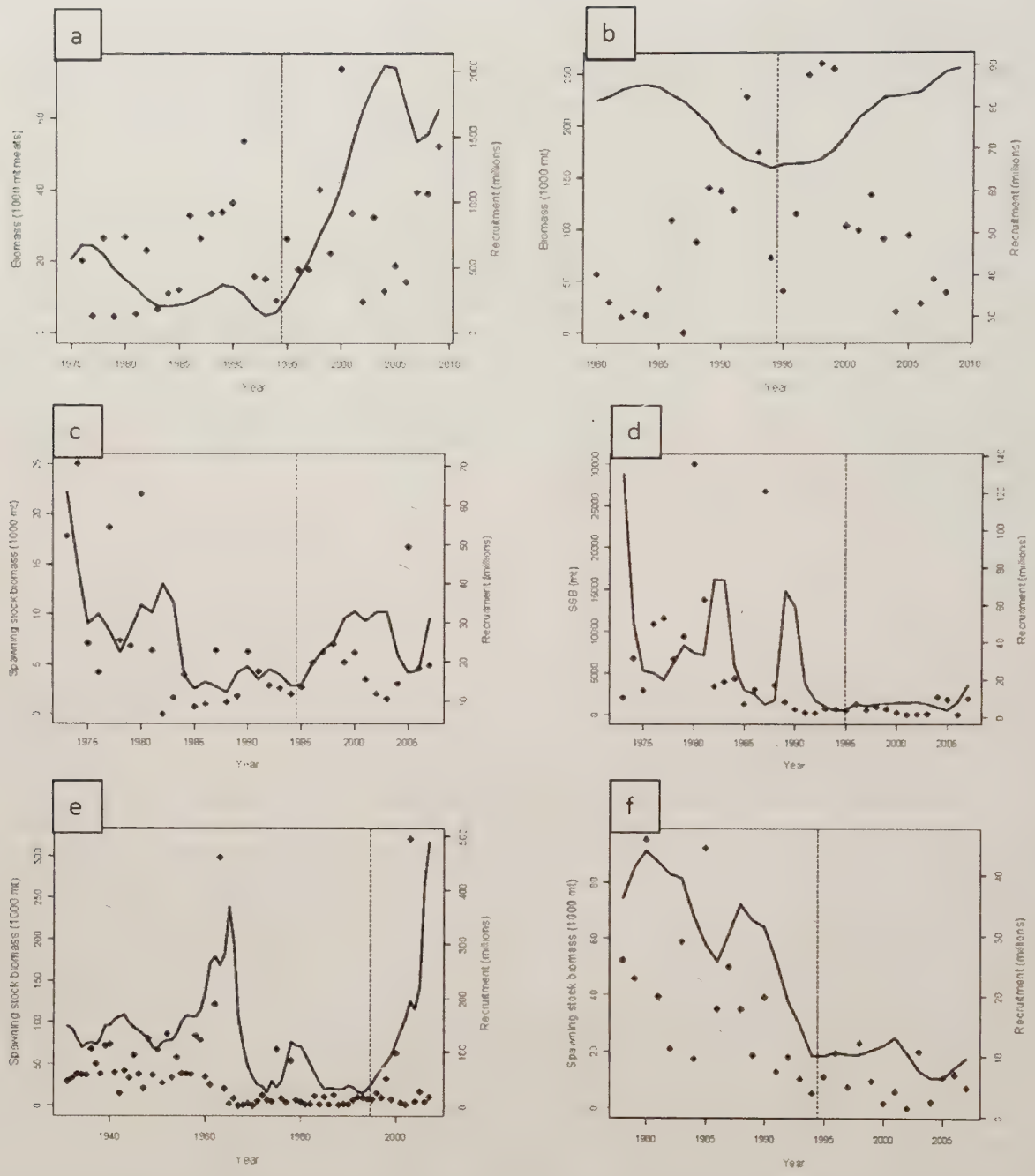

Figure 13.—Estimated biomass (lines) and recruitment (points) for (a) Georges Bank sea scallops, (b) goosefish, (c) Georges Bank yellowtail flounder, (d) southern New England yellowtail flounder, (e) Georges Bank haddock and (note that recruitment is on a log scale) (f) Georges Bank cod, from the latest stock assessment for each stock (NEFSC, 2010, Legault et al., 2011, Brooks et al., table 2, footnote 1; O'Brien et al., text table 2, footnote 2)). The dashed vertical line indicates the time of the closures.

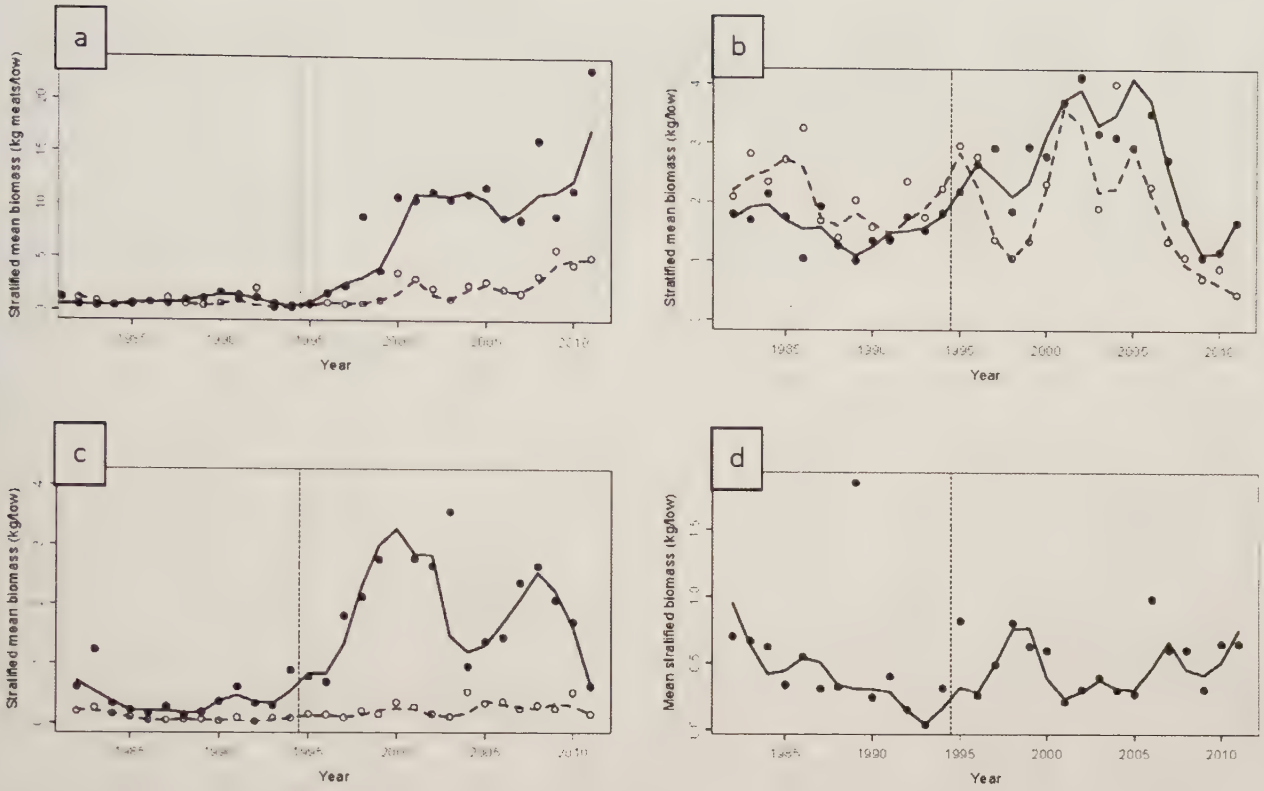

Figure 14. —Biomass indices for closed (solid points) and open portions (open circles) of Georges Bank and surrounding areas for (a) sea scallops, (b) goosefish, (c) Georges Bank yellowtail flounder, (d) southern New England yellowtail flounder. The solid and dashed curves are lowess smoothed versions of the closed and open data, respectively (span = 0.2). The dashed vertical line indicates the time of the closures.

Habitat Conservation MPA's

The habitat conservation MPA's discussed in this paper (vulnerable habitat in the Barents Sea, sandeel spawning areas in the North Sea, and coral closures and Steller sea lion trawl exclusion zones in the Aleutian Islands) have several common features. The MPA's designed for conservation are found in areas with many cold water coral and sponges, which are vulnerable to the impacts of bottom trawling. In the case of the SSL, even though the trawl exclusion zone was intended to reduce fishing mortality on SSL prey, the habitat associated with SSL prey species was also protected.

For MPA's designed to protect habitat and preserve ecosystem functioning, monitoring may be viewed as unnecessary since the main goal is to prevent the disturbance that the reserve itself is guaranteeing. Without monitoring, though, it is not possible to evaluate if a closure had the intended effect and if it affected other ecosystem functions as well. In the case of the protection of prey species for SSL, the monitoring of prey abundance revealed that the effectiveness of the exclusion zone depended on the extent of movement of fish across the exclusion zone boundary. However, because the exclusion zones reduced fishing mortality of the major SSL prey species, Atka mackerel, and protected their spawning and nest guarding habitat, it might have had a positive effect on the reproductive success of this species (Cooper and McDermott, 2011). A similar effect was observed for the sandeel, where the protected areas ensured continued recruitment while the spillover of the fish from the closed areas potentially contributed to the fisheries catch in the open areas. These results may mitigate the short-term impacts of a fishery to local aggregations by protecting habitat critical for spawning or nest guarding.

Fisheries Management MPA's

Responses to fishery closures depend on a number of factors. The first factor is the depletion level of the stock when closures are implemented. Because biomass within the closures cannot increase on average higher than virgin level (assuming unchanged carrying capacity for the stock), larger increases inside the closures can theoretically occur for heavily fished stocks than for those that are lightly fished. In addition, increased adult mobility will allow for emigration into fished areas and therefore negate the closure effect. Species of moderate mobility

Table 2.—Characteristics of the six stocks examined here (Georges Bank cod, haddock, yellowtail flounder, southern New England yellowtail flounder, goosefish (combined southern and northern stocks), and Georges Bank sea scallops. The columns give fully recruited preclosure fishing mortality F_{pc}, computed as the mean of the fishing mortalities between 1992–1994, the current estimate of F_{MSY}, estimated preclosure biomass (B_{pc}, in t) in 1994, the current estimate of B_{MSY}, and the ratios of F_{pc} to F_{MSY} and B_{pc} to B_{MSY} prior to the closures in 1994. All estimates are from the most recent stock assessments for these stocks (NEFSC, 2010; Legault et al., 2011; Brooks et al., 2012; O'Brien et al., 2012).

Stock	F	FMSY	F/FMSY	B	BMSY	B/BMSY
GB cod	1.07	0.25	4.28	18538	248048	0.13
GB haddock	0.46	0.35	1.31	20406	158000	0.13
GB yellowtail	1.50	0.25	5.91	2823	43200	0.07
SNE yellostail	1.72	0.24	7.20	1308	7790	0.17
Goosefish	0.29	0.37	0.78	160000	129002	1.24
GB Scallop	1.07	0.25	418	5719	45838	0.12

may increase in abundance if at least a portion of the fish remain within the closure, but the population increase will likely be less than that of stationary species because some migration of individuals from the closures to the fished areas will occur. Finally, if the closures induce an increase in spawning stock biomass, they may also increase recruitment; this is often termed larval spillover (Planes et al., 2009).

The condition where expected recruitment is well below the level that would produce maximum sustainable yield is often referred to as "recruitment overfishing." Increases in recruitment can only be expected if the depletion level and mobility of the stock allow for considerable increases in biomass inside the closures, and recruitment overfishing was occurring prior to the areas being closed. When both of these conditions are met, increased recruitment and reduced fishing mortality can result in a large increase in biomass inside the MPA. However, closures can increase fishery yield only when the stock is recruitment overfished (Hart, 2006)

Consistent with these ideas was the response of some of the fish stocks described in this paper. Sea scallop biomass in New England, lobster biomass in Norway, and sea peach abundance in the eastern Bering Sea increased inside the closures because they had been depleted and are not very mobile. On the other hand, Georges Bank Atlantic cod and Bering Sea Pacific cod appeared to show no response to the closures, likely because of higher mobility between open and closed areas. Goosefish showed a modest response to the closures, likely due to low fishing effort and moderate mobility.

Biomass and recruitment of Georges Bank haddock has increased greatly since the closures, due to the combination of its severe depletion level prior to the closures, moderate mobility, and clear evidence of recruitment overfishing. The MPA's may have been particularly important for haddock in the first 5–10 years after the closures. Norwegian sandeel and Aleutian Islands Atka mackerel benefited from the closures presumably because reproductive success was ensured by protecting spawning habitat and larval spillover contributed to recruitment in the fished areas as well.

The response of yellowtail flounder stocks in New England and flatfish and invertebrate species in the eastern Bering Sea to the closures were mixed. It is possible that the closures for yellowtail flounder in New England pushed effort towards the more productive areas and thus may have contributed to the observed declines. Closures in the Bering Sea seemed to be positive for more than half of the flatfish cases examined, but not in all areas. The crab species in the Bering Sea for which these closures were originally designed did not benefit from the closures. In fact, several crab species exhibited declines in abundance. This was most likely due to the fact that directed fishing for these species was not reduced, only bycatch of crabs in the trawl fisheries targeting other species. These closures most likely did not reduce overall fishing mortality

Table 3.—MPA design considerations.

MPA type	Goal	Species characteristics	Area closure characteristics	MPA management
Habitat Conservation MPA	Habitat preservation to void/reduce human impact on habitat	Species associated with certain habitat types Species remain within boundaries of MPA	Needs to encompass desired habitat types (e.g., unique characteristics which support high biodiversity or high recreational value)	Enforcement necessary; easier to achieve when effort redistribution effects are not large
Fishery Management MPA (rebuild age structure)	Increase yield through the growth of larger individuals	Spillover effect of large adult individuals; small adult movement	Needs to encompass local population; rotational closures can be effective	Enforcement necessary; additional quota/effort management needed to prevent overfishing in adjacent open areas; fishing the line likely
Fishery Management MPA (larval spillover effect)	Enhance recruitment in exploited areas	Large larval movement; small adult movement	Needs to encompass local population, spawning grounds and/or nursery area	Enforcement necessary
Fishery Management MPA (minimize exploitation rate)	Rebuild stock (recent crash) by minimizing exploitation rate	Small adult movement Large larval movement Spillover effect of adult fish into open area	Needs to encompass large enough area to ensure successful local recruitment.	Enforcement necessary; additional quota/effort management needed to prevent overfishing Potential effort reduction necessary due to smaller fished area; fishing the line likely
Fishery Management MPA (protect spawning grounds)	Sustainable production, and to prevent recruitment overfishing	Species well-defined spawning aggregations and seasons	Spawning grounds can be closed seasonally or locally and still allow fishery to occur outside of closed area/season	Seasonal enforcement necessary; more challenging to gain fishery support when there is a roe fishery.

enough for the crab stocks to increase in abundance.

MPA Design

Habitat Conservation MPA's

In this paper we show two approaches to designing MPA's for habitat closures. The first approach was the identification and mapping of vulnerable habitat in the Barents Sea and included a precautionary closure. This was followed by the implementation of better directed closures to protect the most valuable and vulnerable areas based on the knowledge gained with the habitat mapping project. The challenge here is twofold. First, it is necessary to clearly identify "vulnerable areas" and distinguish them from surrounding areas. Because vulnerable habitat often occurs in a large enough percentage of the total habitat to preclude closure of all vulnerable habitat, the second challenge is for managers to implement the closures in a manner which balances the ecological and economic impacts of the closures. This approach can work well if management decisions on closure locations are informed by science and formal risk analyses, rather than by political pressure from user groups.

The second approach discussed is to close areas that have not been previously exploited. This approach enabled MPA's to be implemented for the Aleutian Island coral areas without extensive seafloor mapping. Since these areas had not yet been exploited by the fishery (mainly because bottom conditions precluded the use of typical trawl gear on a practical basis), potential economic loss to the fishery was minimal and the fishing industry was cooperative in establishing these closures. These closures might not have been so well received if the fishing industry or the oil and gas industry would had seen a significant future benefit in exploiting those areas. The success of this approach is based on finding sensitive and ecologically valuable areas that have not been exploited and therefore are easier for the resource users to "give up."

Fisheries Management MPA's

Another scenario often encountered by managers are spatial closures to address fisheries management concerns. Examples discussed here are the sandeel in the North Sea, the lobster and Atlantic cod in Norway, the groundfish and scallop closures on Georges Bank, the closures in the Eastern Bering Sea for crab bycatch, and the Steller sea lion trawl closures in the Aleutian Islands.

One goal in the design of these closures was to encompass as much of a declining stock as possible, while still allowing a commercial fishery to take place. This is usually a response to a crisis that has to be addressed quickly and may not allow for a careful precautionary approach when designing an MPA.

In many cases, MPA's are based on fishing information and/or survey information regarding areas of species abundance and population decline. As in the examples above, these MPA's often encompass some or all of the preferred fishing grounds. This approach is viable if the protected species have moderate mobility such that population increases in the protected area spill over into fished areas and increase yield, and if the recovery is not hindered by impacts in other stages in the species' life cycle (e.g., reproduction, nursery habitat). For this reason, it is important to understand ontogenetic habitat use and the life history strategy of the species to be protected.

The two main approaches to the design of an MPA (Conservation vs. Fisheries Management) are outlined in Table 3, including the appropriate goals, the characteristics most likely to render a species a candidate for MPA management, the characteristics of the habitat and, finally, the level of MPA management suggested to achieve the desired goals.

MPA Monitoring

Monitoring the successful achievement of MPA goals can be time-consuming and labor intensive. In the cases presented in this paper, only two MPA's had a dedicated monitoring scheme (the lobster reserves in Norway and the Steller sea lion trawl exclusion zones in Alaska). While many species associated with the MPA's considered here have estimates of abundance available from fishery stock assessments, this information is only available at spatial scales much larger than the MPA—rendering evaluation of the MPA difficult.

As such, the success of spatial management measures such as fishery closures is often difficult to measure. In order to evaluate the success or failure of an MPA as a management tool, it should be stressed that, although data can be expensive to obtain, monitoring is an important part of the feedback loop (Jones et al., 2011). For a relatively sessile species like the Norway lobster, closing a small "test area" to fishing in a place that is easy to monitor can be a first step in developing a monitoring program for an MPA. Stocks, such as Pacific and Atlantic cod, that undergo long migrations and/or have large spatial distributions will probably require large closed areas and will require more resources to monitor effectively. Monitoring adults stock using tools such as tagging programs, will give insight into the effects of movement across the boundaries of areal closures on adult biomass. On the other hand, it may be difficult to distinguish the effects of larval spillover from an MPA from other factors influencing larval survival. Thus, it is essential to include a well-designed monitoring and evaluation program in an MPA management plan.

In addition to research monitoring of the ecosystem it is also essential to establish enforcement monitoring. In many U.S. Federal fisheries in Alaska and Northeast Atlantic, fishing vessels have been equipped with satellite vessel monitoring systems that enable managers to track fishing vessels in real time. This monitoring can ensure compliance around MPA boundaries; however, enforcement can often be more complicated than just tracking presence or absence inside closed areas. Enforcing gear compliance can be

more challenging and often requires close monitoring of activities, which can be accomplished by an observer program such as the ones used for fisheries in the U.S (Faunce and Barbeaux, 2011) or increasingly effective electronic monitoring programs.

Side Effects of MPA's

Area closures can have unexpected consequences affecting both stocks and the economics of the fishery. In cases where implementation is not accompanied by an overall reduction in fishing effort, MPA implementation can result in intensified fishing outside the closed areas because the fishable grounds have been reduced. This may result in increased exploitation and reduced biomass outside the closures, potentially offsetting increases within the closures, and may result in localized overfishing if fish migrate outside the closed area and are disproportionately captured at the borders of the MPA. This may have occurred for Atlantic cod in the North Atlantic and yellowfin sole in the Bering Sea. The positive effect of the closures would then be directly correlated to the movement behavior of the protected species and the fishing intensity outside the MPA.

Displacement of fishing effort may also result in undesired bycatch, which occurred when fishing effort displaced by the Bering Sea crab MPA's resulted in an increase in halibut bycatch (Abbott and Haynie, 2012). Side effects of MPA's are often difficult to predict so it is important to study potential aspects of closures and incorporate a feedback loop into an adaptive management scheme. Unwanted side effects can be better anticipated by considering fleet dynamics and can be mitigated by changes in the MPA design or other fishery management tools. Most MPA designs should not be considered static but flexible, allowing for continuous improvement through monitoring, evaluating, and adjusting the design and management strategy. Finally, not all side effects may be negative. When the closure to protect vulnerable marine ecosystems (VME's) also includes essential fish habitats, such as coral reefs, it can have an additional benefit for fish species thriving in the VME (Buhl-Mortensen et al., 2010).

Challenges for Northern Region MPA's

MPA's in northern regions present specific challenges. The remoteness and size of the areas to be managed often hinder the collection of data at the appropriate spatial scale. The large home range of some of the important commercial species makes them questionable candidates for area closures. In addition, many species' life history traits and their habitat requirements during their early life history are often unknown and might be changing with changing environmental conditions such as global warming.

The complex fisheries management systems in these regions make MPA implementation a lengthy process. However, given all of these challenges, the well-established management and enforcement plans in all three regions discussed in this paper also make it possible to track population status through stock assessments and enforce the closures.

The biggest challenge for MPA's in northern areas will be to include sufficient area to encompass vulnerable species' home ranges without excessive monitoring costs or fishery impacts. Quota management and effort allocation may still be the most effective management tools used in these areas, with MPA's supplementing these tools where appropriate.

Conclusions

MPA's can be effective management tools when the areas are designed with clear goals, the species to be protected are sufficiently concentrated within the closed areas, and the MPA design is based on scientific information rather than simply the path of least resistance to user groups. The most successful fisheries management MPA's were for low mobility species of depleted stock status that stayed within the MPA, such as the North Atlantic scallops, haddock, and Norwegian lobster. The least successful MPA's included species that moved freely across boundaries, such as the Northeast Atlantic and Bering sea cod. Successful MPA's for increasing reproductive success worked well when critical spawning or nursery ground were protected, such as the sandeel and Atka mackerel spawning and nesting areas. Habitat protection MPA's need enough scientific information to identify vulnerable habitat, which often is a costly process.

In recent years, frameworks have been established to assess and evaluate MPA's, and can be useful tools to guide the monitoring process and adjust management plans in a structured manner (Buhl-Mortensen et al., 2017). The MPA's examined in this paper were developed for a wide variety of purposes. While no case studies presented here have shown significant negative impacts of MPA's on either habitat or species to be protected, the observed benefits of these MPA's have been mixed and in some cases there have been unanticipated negative consequences.

Some MPA's were implemented because they were the most attractive means available to achieve conservation or a fisheries management goal, but the net benefits and costs of these MPA's remain unclear.

Conservation MPA's such as the Aleutian Island coral closure are conceptually easy to design and would be easy to implement if there were no conflicting claims on the area by user groups. This is rarely the case, however, and real-world MPA's usually involve economic and political trade-offs. Even defining success for an MPA is not always straightforward, as the goals of the MPA may be complicated and multifaceted. Similarly, monitoring the impacts of MPA's can be very challenging, especially for multispecies mobile stocks that function as part of a complex and dynamic ecosystem with or without an MPA.

In the MPA's examined for those stocks, success was most evident for low-mobility species in small closures and for habitat closures where removing fishing impacts are the primary

goal of the closure. In light of the increasing attention MPA's have received in recent years with respect to both conservation and fishery management, MPA's should not be regarded as the solution to all problems but merely as one of several tools used for successful fisheries management.

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The Manuscript

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Manuscripts must be double-spaced throughout, and a complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e., there can be no subdivision without at least two items).

Style

The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (2008 ed.) and the Scientific Style and Format: the CSE Manual for Authors, Editors, and Publishers (2014, 8th ed.) published by the Council of Science Editors.for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 November 2013. Measurements should be expressed in metric units, e.g., metric tons as (t); other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g. ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lower-case el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g., nine fish but 9 mm).

Footnotes

Footnotes should not be embedded within the text document. They must be numbered with Arabic numerals and listed separately. Footnote all personal communications, unpublished data, and unpublished manuscripts with full address of the communicator or author, or, as in the case of unpublished data, where the data are on file. Authors are advised to avoid references to nonstandard (gray) literature, such as internal, project, processed, or administrative reports, wherever possible. Where these references are used, please include where they may be located (website or public depository).

Tables

Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but ample enough to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

Literature Cited

Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1979a, 1979b, 1979c, etc.). Authors must double-check all literature cited; they alone are responsible for its accuracy.

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Figures

Figures must be cited in numerical order in the text. Use Times Roman font (upper and lowercase letters) to label within figures. Avoid vertical lettering except for y-axis labels. Zeros should precede all decimal points for values less than one. Figure legends should explain all symbols and abbreviations and should be double-spaced on a separate page at the end of the manuscript. Consider column and page sizes when designing figures. Please note that we do not print graphs in color.

Finally

Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission.

Email or mail the manuscript to: Editor, Marine Fisheries Review, Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115 (Willis.Hobart@noaa.gov and cc: the Managing Editor, Jacki.Strader@noaa.gov).

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